Green TVWS

School on Applications of
Open Spectrum and White Spaces Technologies

ICTP Trieste

12 March 2014

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Network Startup Resource Center NSRC
IT University of Copenhagen

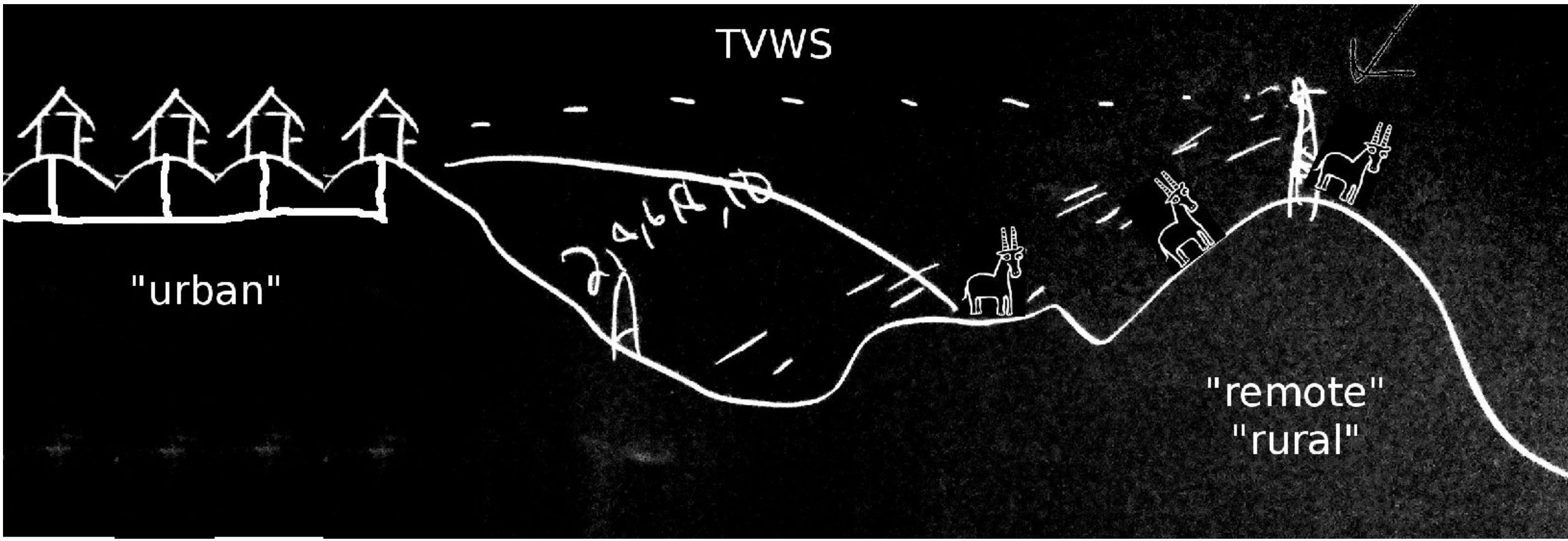
What is this Talk about?

Green TV White Spaces

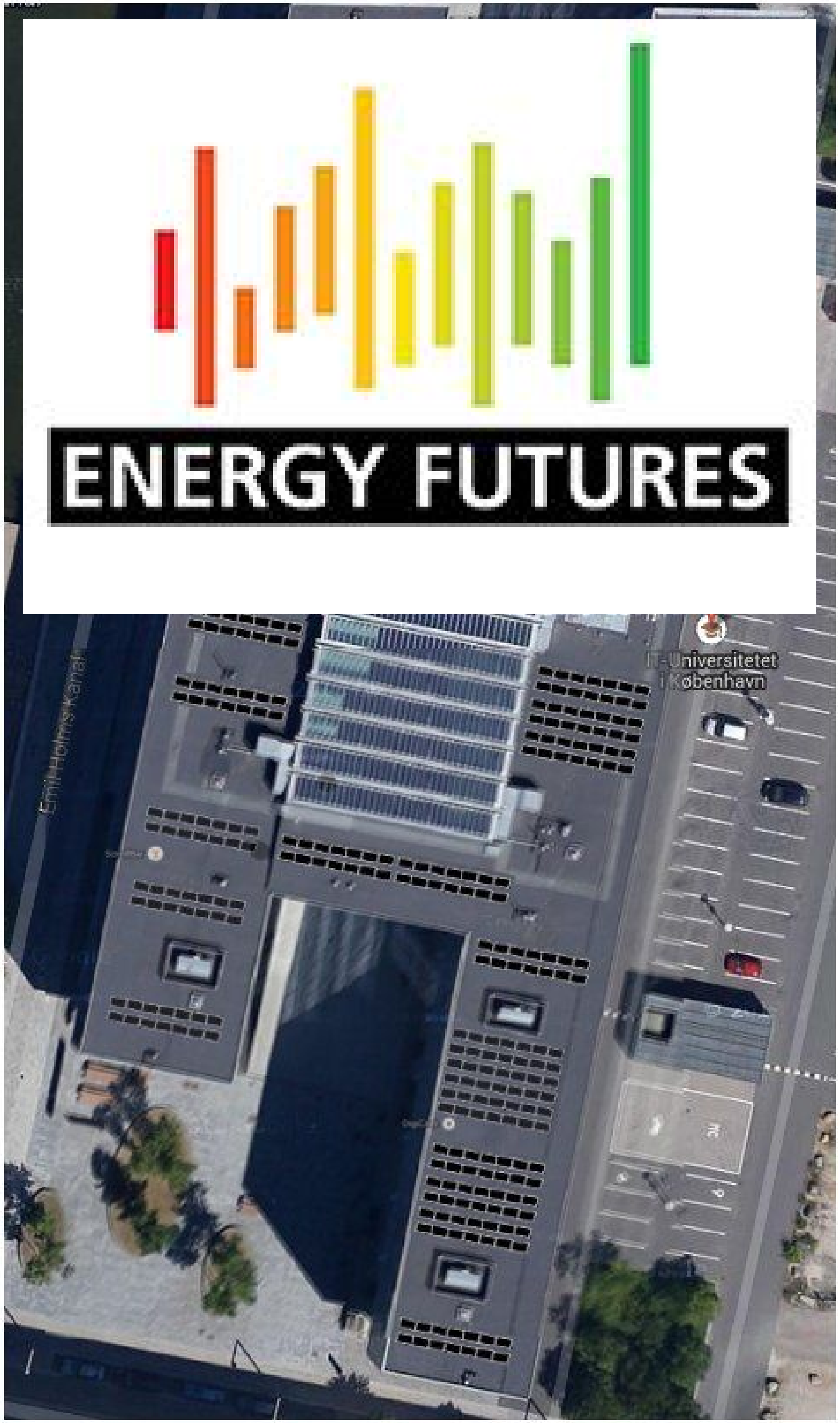
~~Green TV White Spaces~~

Sustainable
Intelligent
Autonomous
Economically attractive
Power

for (more than just) IT networks


TVWS
"urban"
"remote"
"rural"

My background



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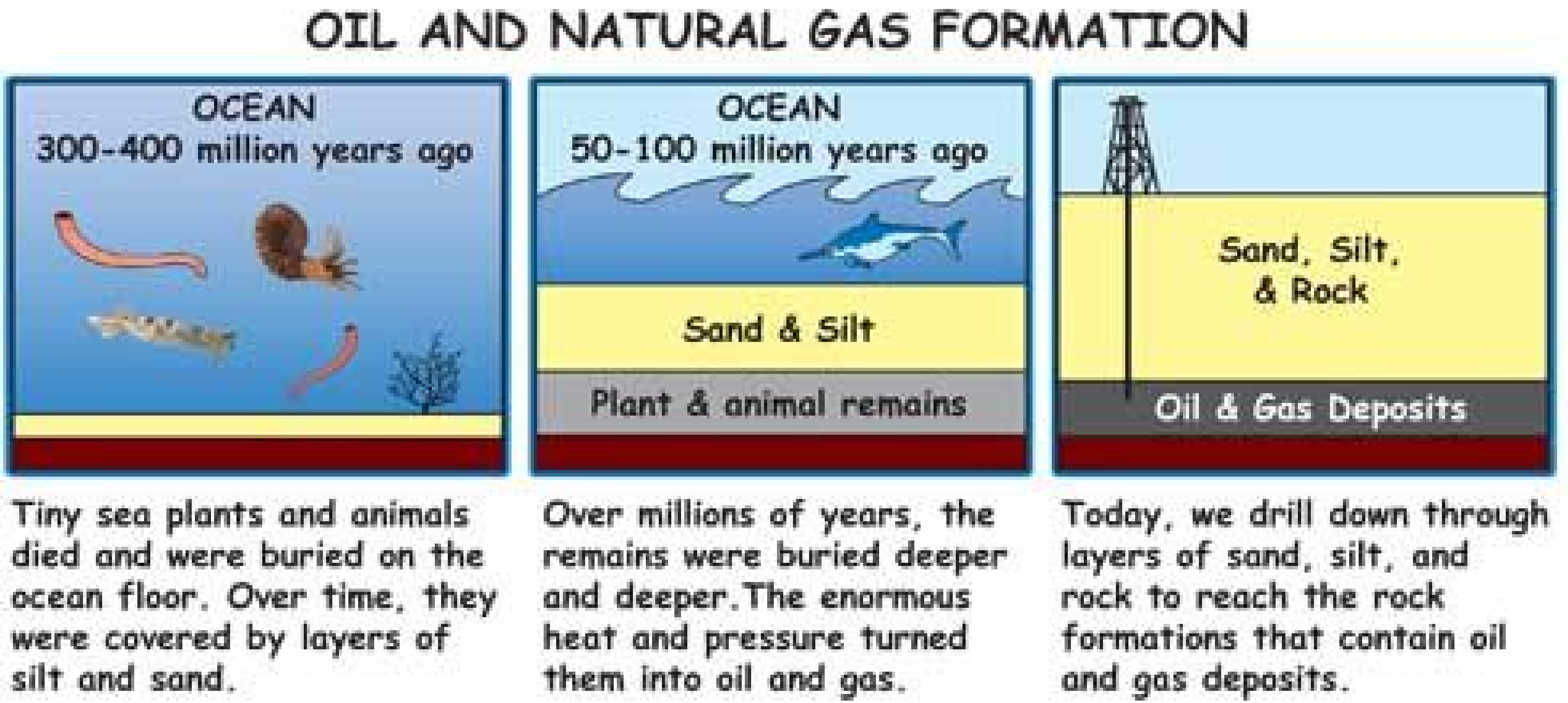
Background


OIL


OIL AND NATURAL GAS FORMATION
OCEAN
300-400 million years ago
OCEAN
50-100 million years ago
Sand & Silt
Plant & animal remains
Sand, Silt, & Rock
Oil & Gas Deposits
Tiny sea plants and animals died and were buried on the ocean floor. Over time, they were covered by layers of silt and sand.
Over millions of years, the remains were buried deeper and deeper. The enormous heat and pressure turned them into oil and gas.
Today, we drill down through layers of sand, silt, and rock to reach the rock formations that contain oil and gas deposits.

What all fossile energy sources have in common:

They are finite.

But we will find more?

We will. But that does not matter much.

Sustainable energy

Solar

  Photovoltaic

  Thermal

Wind

Hydro ... & hybrid solutions

Wave, Tidal

Geothermal

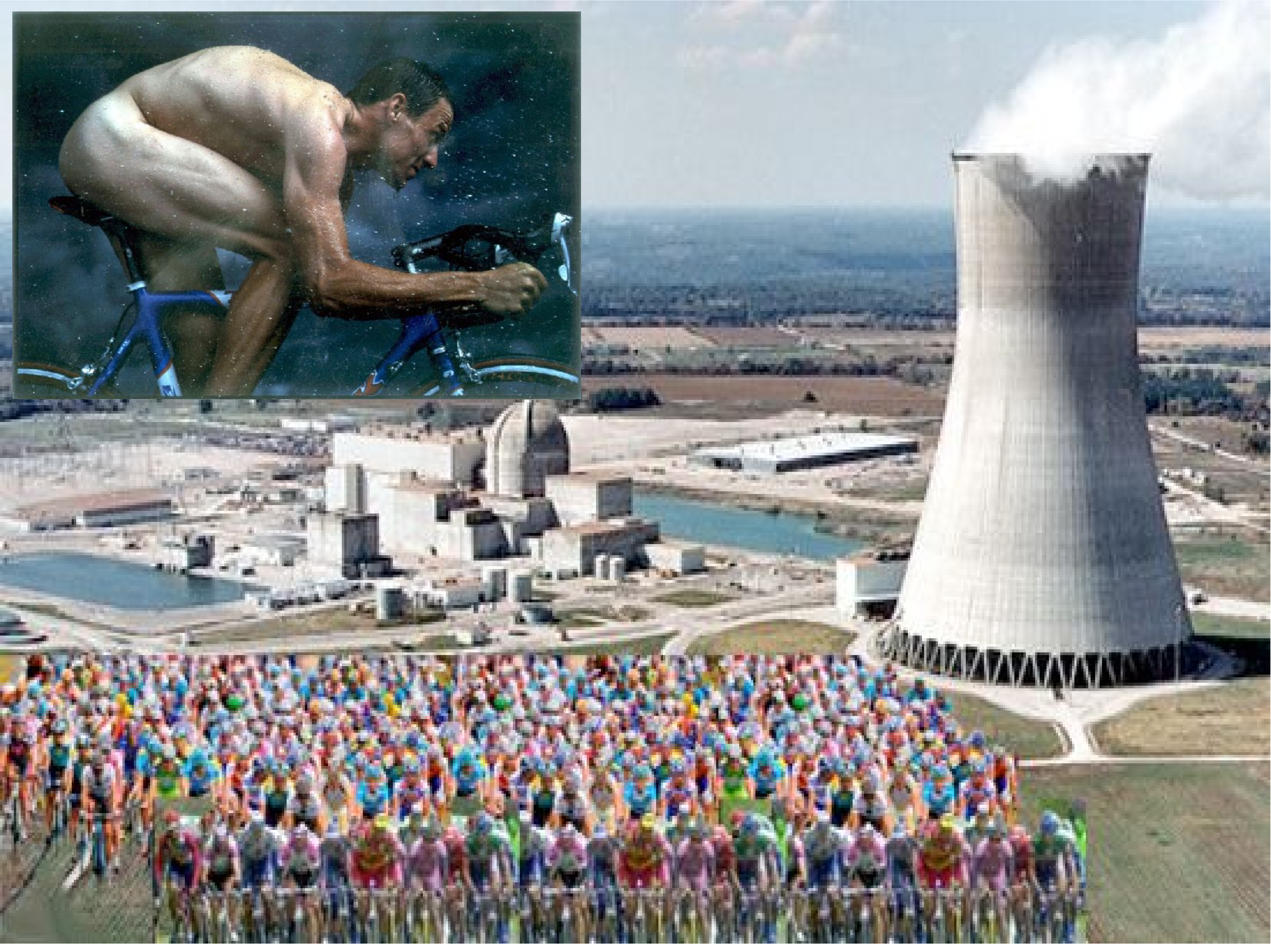
Other forms of harvesting:

  Vibration

  Bio-mechanical

  Radiation

Human power

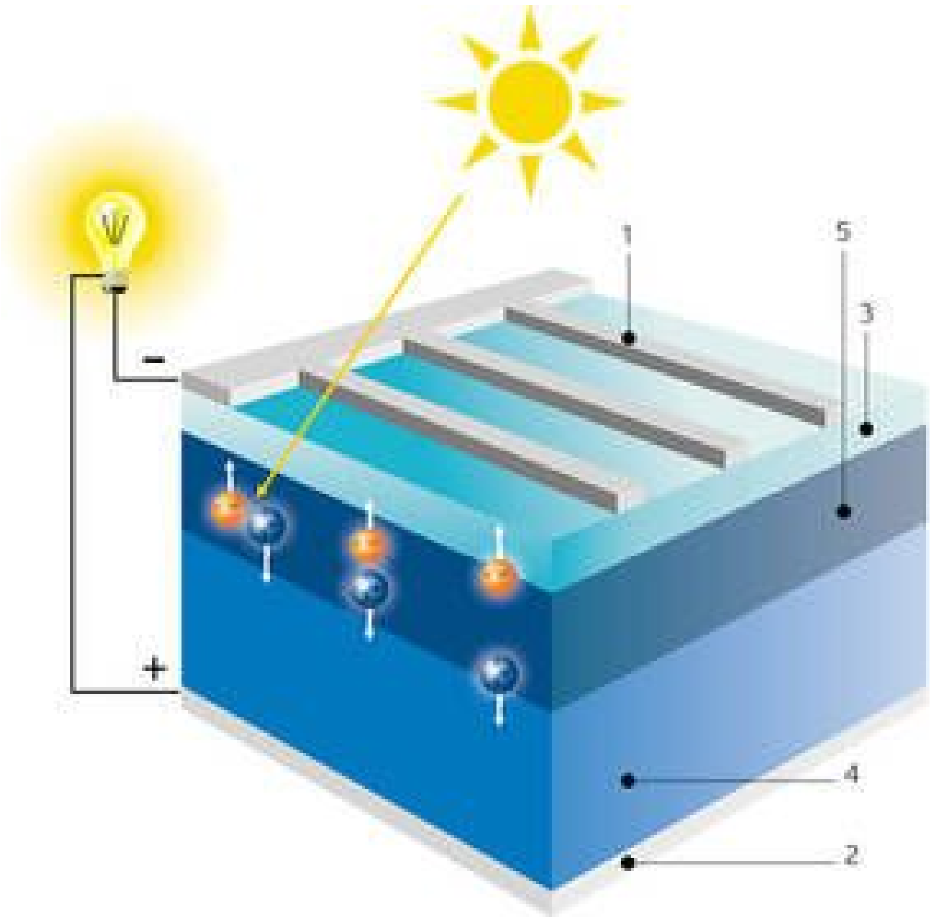


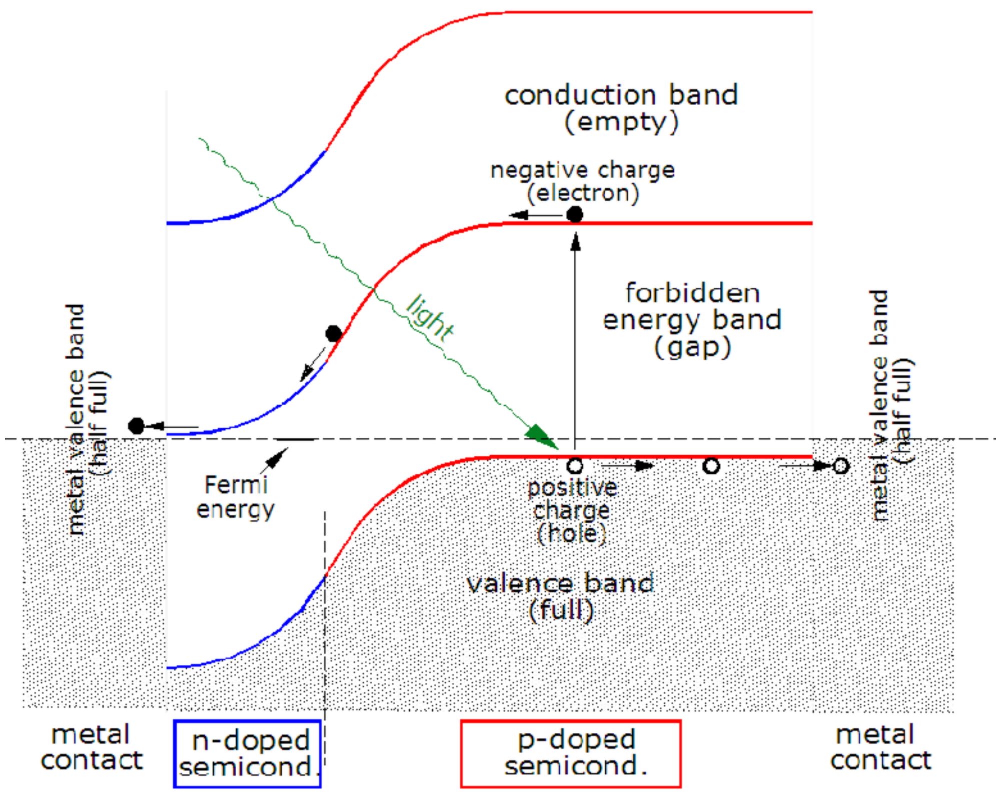
Sustainable energy

Small wind turbines

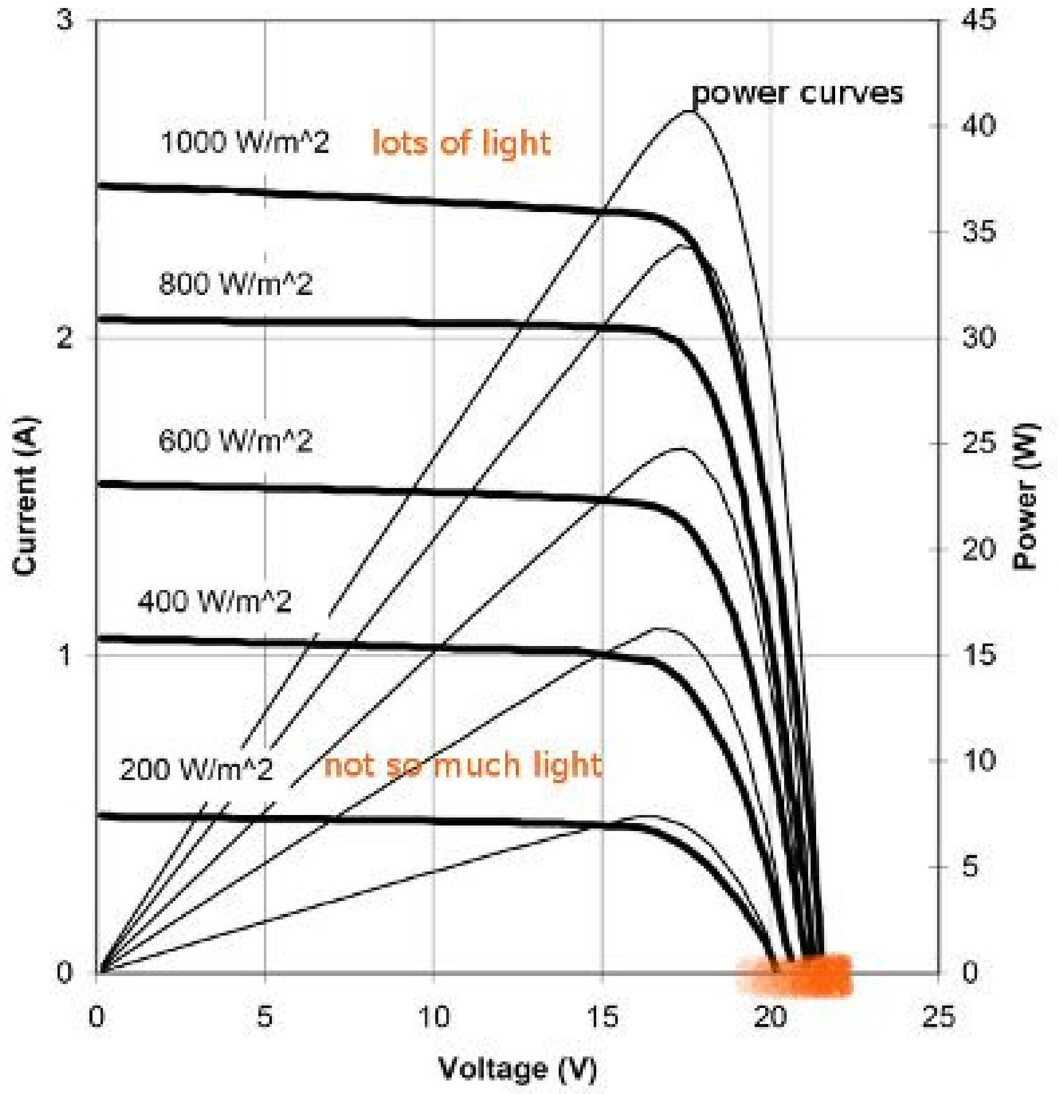
< $1 / W

Photovoltaics

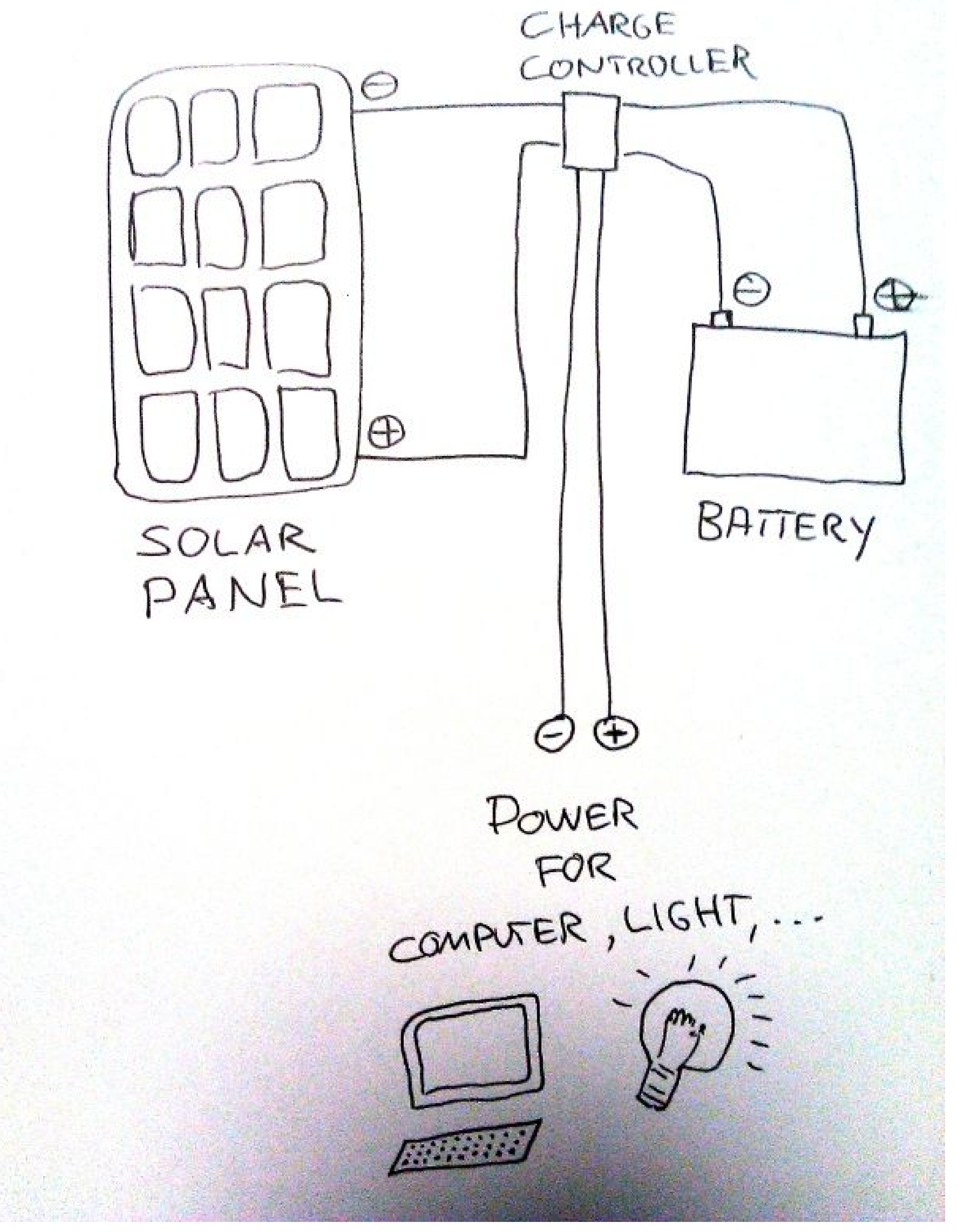




Solar panel: I-V-curves and MPP

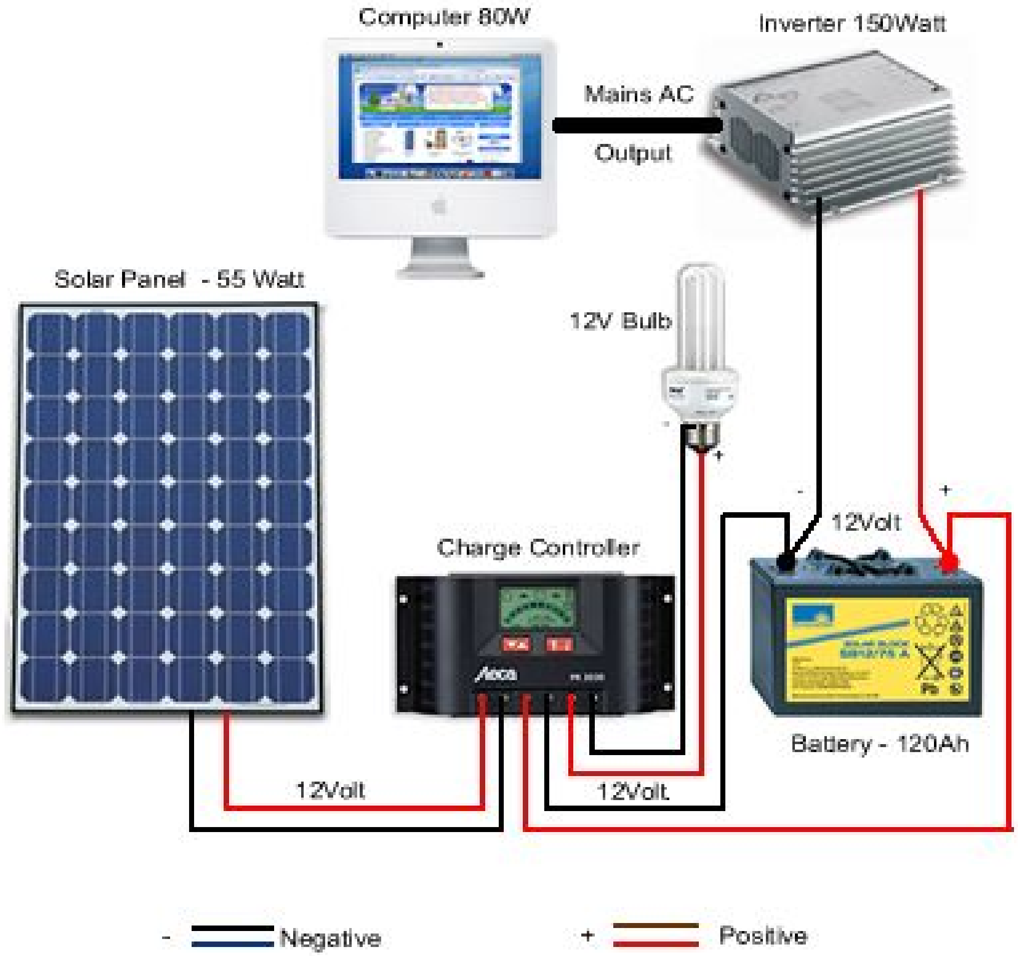


Principle



CHARGE CONTROLLER
SOLAR PANEL
BATTERY
POWER FOR COMPUTER, LIGHT, ...

Principle



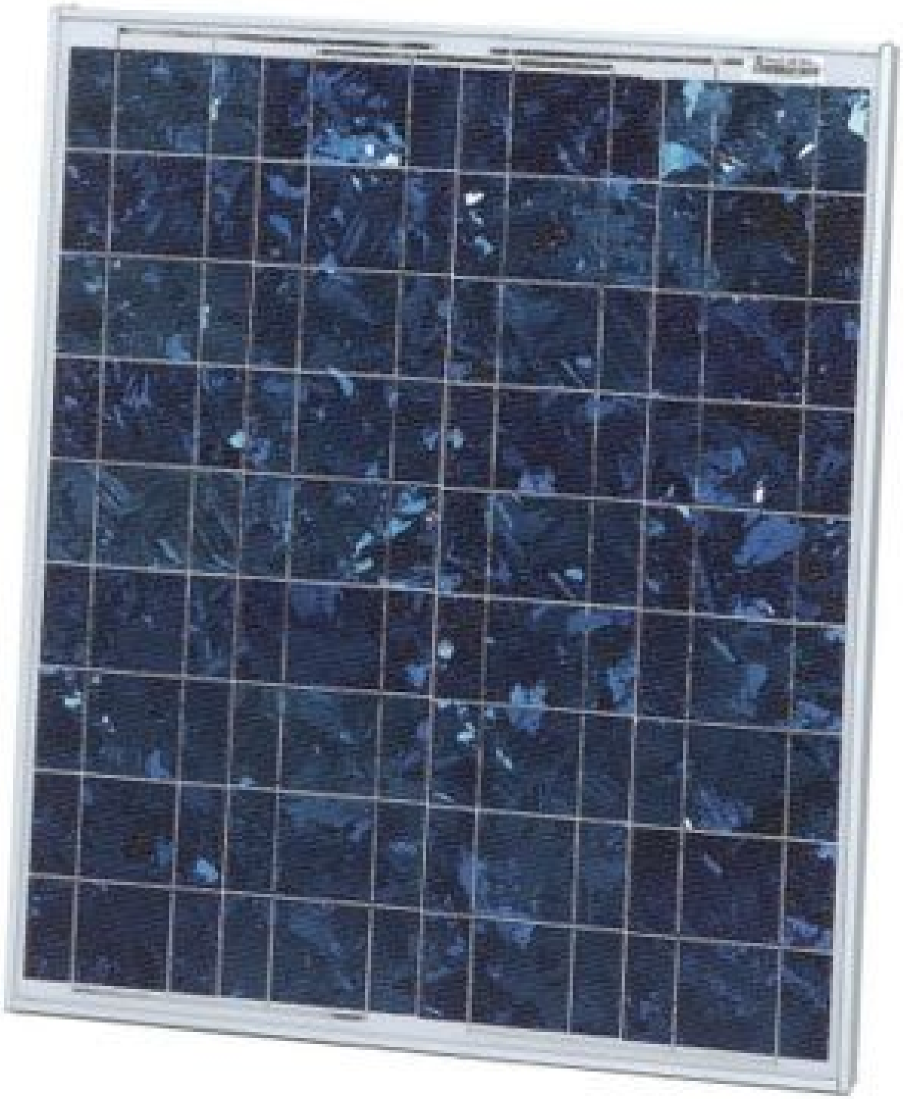
Computer 80W
Inverter 150Watt
Mains AC
Output
Solar Panel - 55 Watt
12V Bulb
12Volt
Charge Controller
Battery - 120Ah
12Volt
12Volt
- Negative
+ Positive

Types of solar cells

Monochrystalline

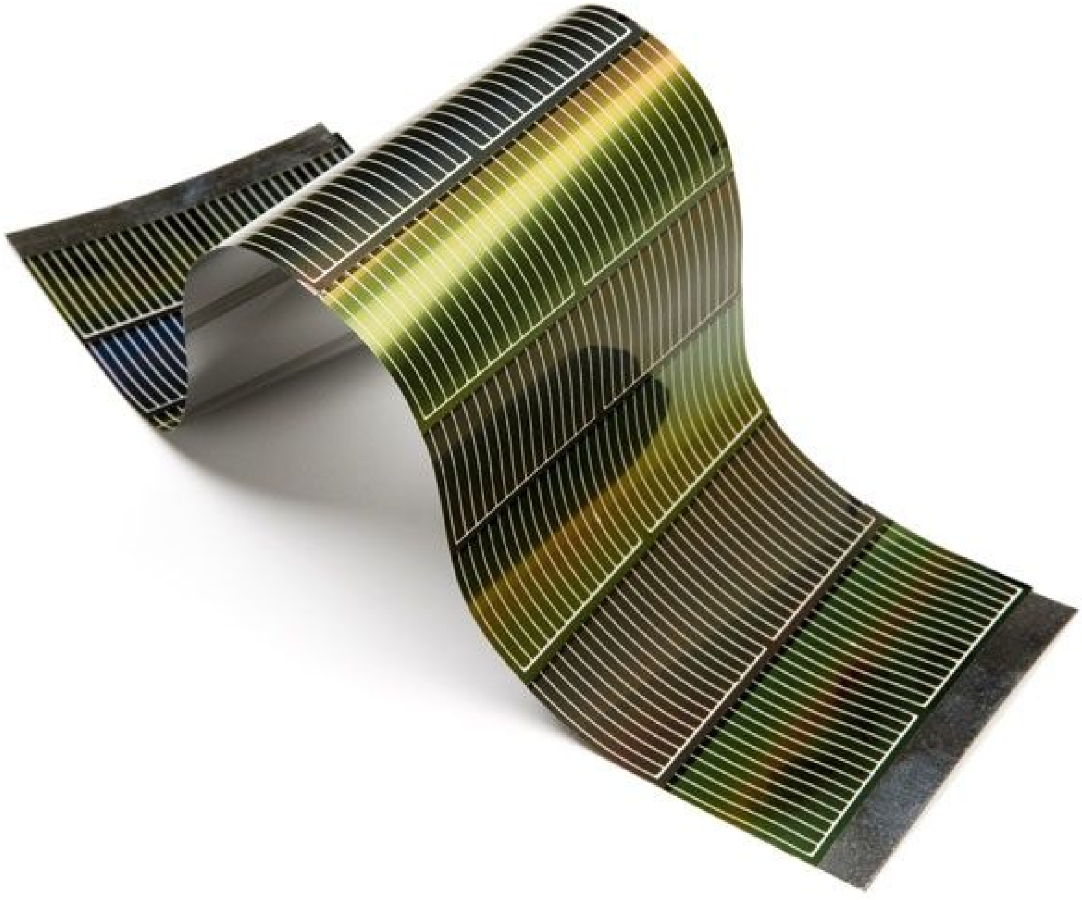
Types of solar cells

Polychrystalline

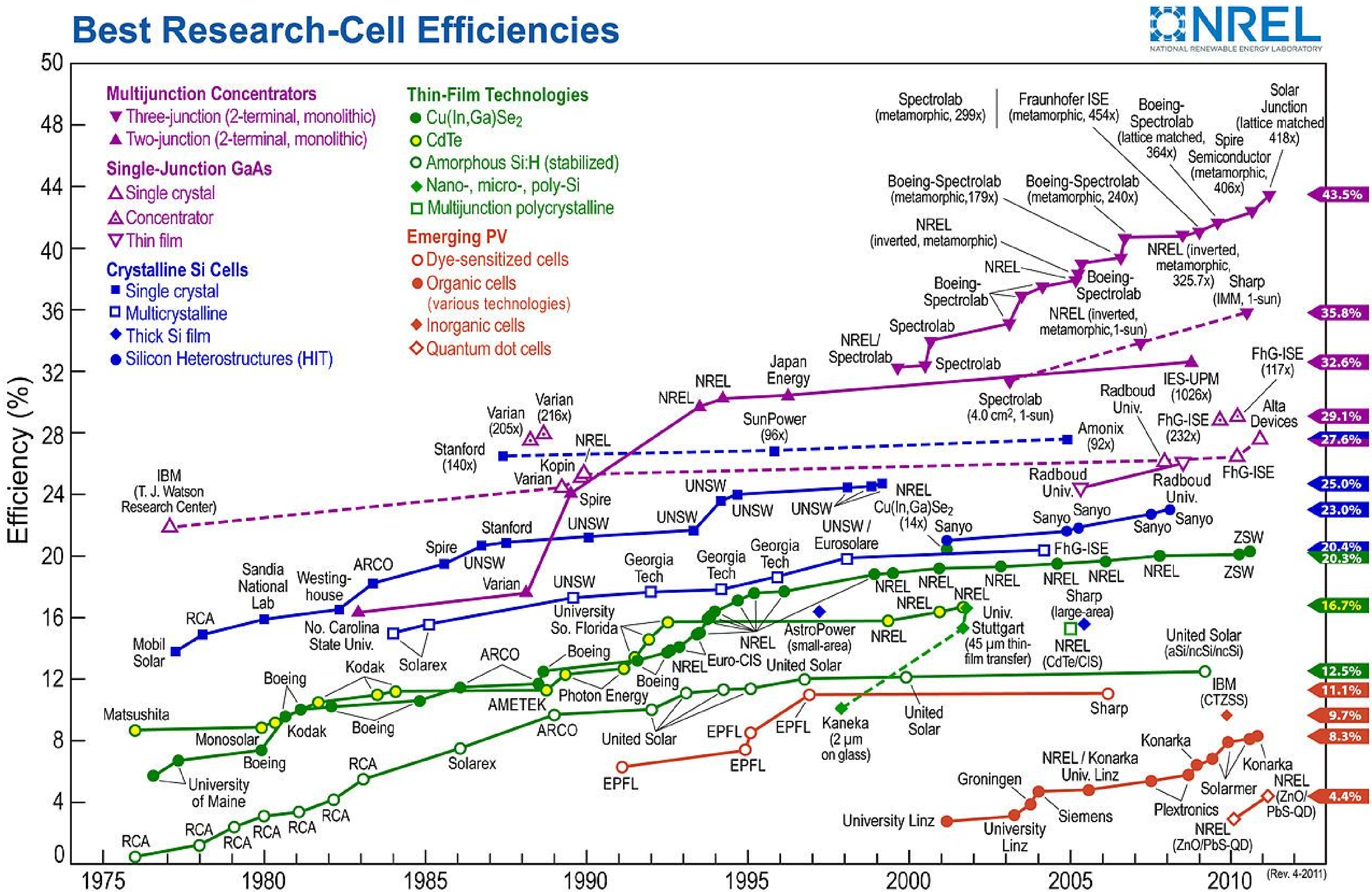


Types of solar panels

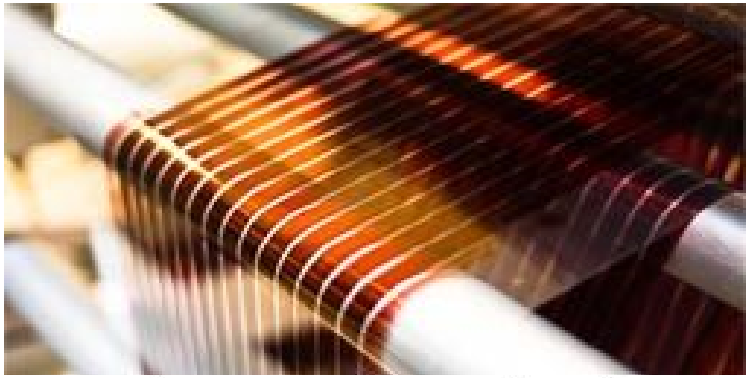
Thin film, CIGS, ...

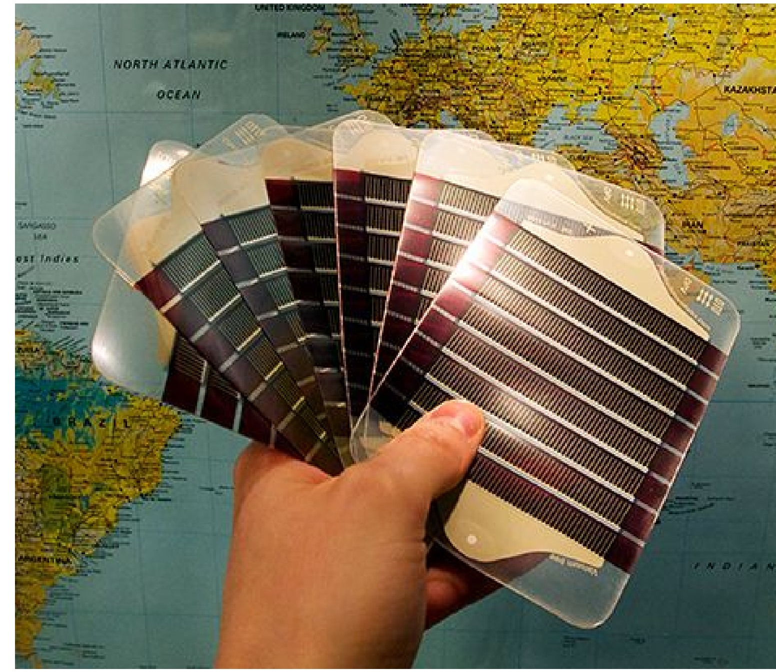


New types of solar cells



New types: organic printed cells



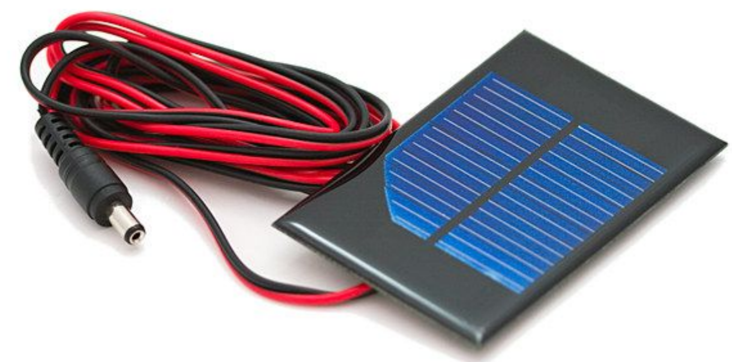


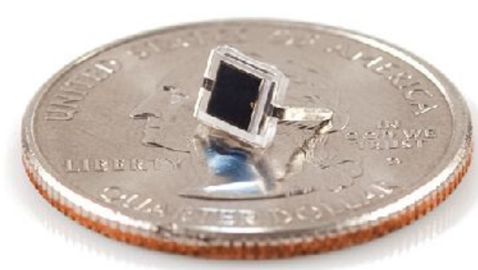
http://plasticphotovoltaics.org/

Note: free online course and free cell samples for education

DTU Denmark

Solar in all sizes





Economics

What is the cost per Watt?

Today,
Solar panels (*in the 100 Watt class!*) cost

< 1 $ per Watt

(you can get quality for **$0.50 per Watt**)

… but smaller cells cost more:

	0.5w Solar Panel 55x70	$2.00
	1.5W Solar Panel 81X137	$6.99
	1w Solar Panel 75X100	$3.50
	2.5W Solar Panel 116X160	$12.90
	2w Solar Panel 80X180	$9.90
	3W Solar Panel 138X160	$14.90
	B-Squares (SOLAR-SQUARE)	$22.50

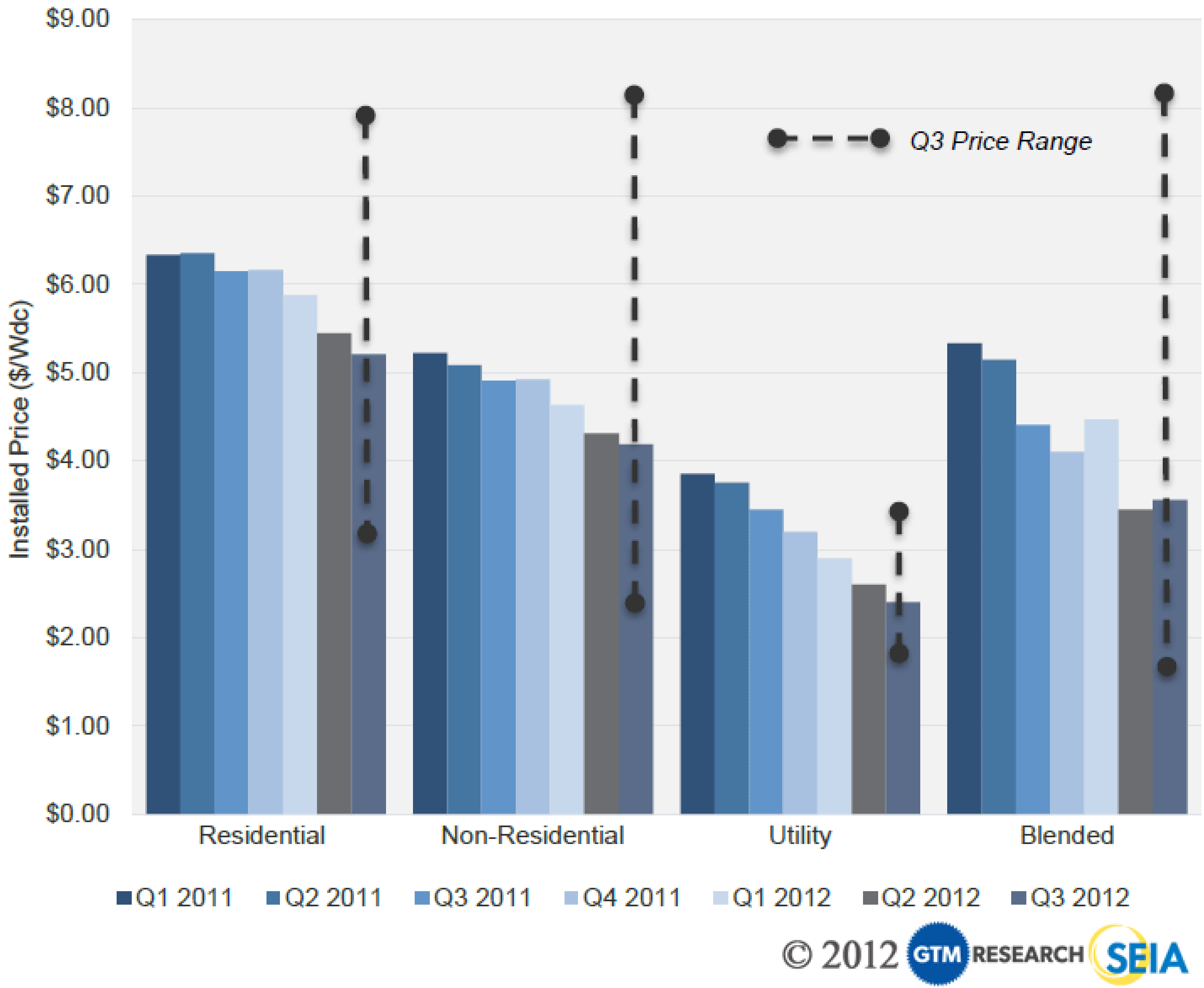
Source: seeedstudio.com

Economics (up against 15 cents/kWh)

Table showing average cost in cents/kWh over 20 years for solar power panels

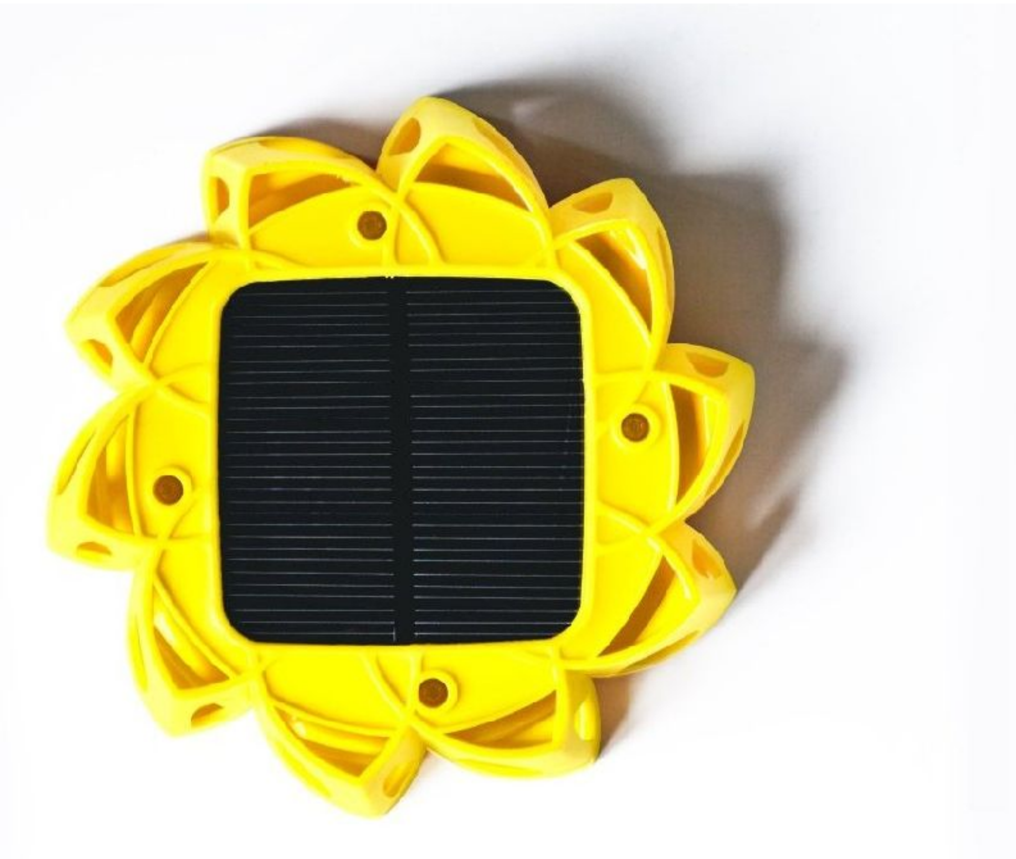
		Insolation [peak sun hours]								
		6				4				2
Cost [$/W]		**2400** kWh/ kWp•y	**2200** kWh/ kWp•y	**2000** kWh/ kWp•y	**1800** kWh/ kWp•y	**1600** kWh/ kWp•y	**1400** kWh/kWp•y	**1200** kWh/kWp•y	**1000** kWh/kWp•y	**800** kWh/kWp•y
	200 $/kWp	0.8	0.9	1.0	1.1	1.3	1.4	1.7	2.0	2.5
0.5	600 $/kWp	2.5	2.7	3.0	3.3	3.8	4.3	5.0	6.0	7.5
1	1000 $/kWp	4.2	4.5	5.0	5.6	6.3	7.1	8.3	10.0	12.5
	1400 $/kWp	5.8	6.4	7.0	7.8	8.8	10.0	11.7	14.0	17.5
2	1800 $/kWp	7.5	8.2	9.0	10.0	11.3	12.9	15.0	18.0	22.5
	2200 $/kWp	9.2	10.0	11.0	12.2	13.8	15.7	18.3	22.0	27.5
	2600 $/kWp	10.8	11.8	13.0	14.4	16.3	18.6	21.7	26.0	32.5
3	3000 $/kWp	12.5	13.6	15.0	16.7	18.8	21.4	25.0	30.0	37.5
	3400 $/kWp	14.2	15.5	17.0	18.9	21.3	24.3	28.3	34.0	42.5
4	3800 $/kWp	15.8	17.3	19.0	21.1	23.8	27.1	31.7	38.0	47.5
	4200 $/kWp	17.5	19.1	21.0	23.3	26.3	30.0	35.0	42.0	52.5
	4600 $/kWp	19.2	20.9	23.0	25.6	28.8	32.9	38.3	46.0	57.5
5	5000 $/kWp	20.8	22.7	25.0	27.8	31.3	35.7	41.7	50.0	62.5

Economics: System cost



Source: http://www.forbes.com/sites/peterdetwiler/2012/12/11/solars-steady-march/

Economics & (non)sense



http://www.littlesun.com

100 little suns = 40 Watt
$3000

$75 / Watt

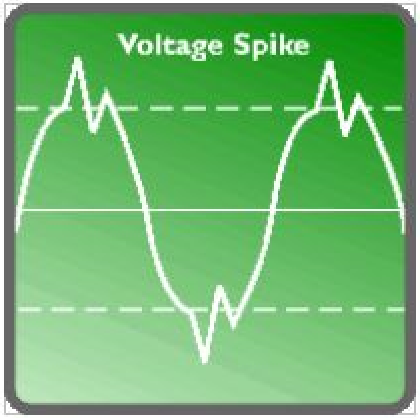
Economics & sense

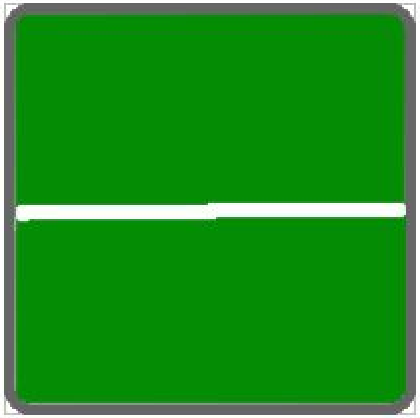
Sunblazer – South Sudan - see http://communitysolutionsinitiative.org/

Economics & sense

Sunblazer – South Sudan - see http://communitysolutionsinitiative.org/

Power & ICTs

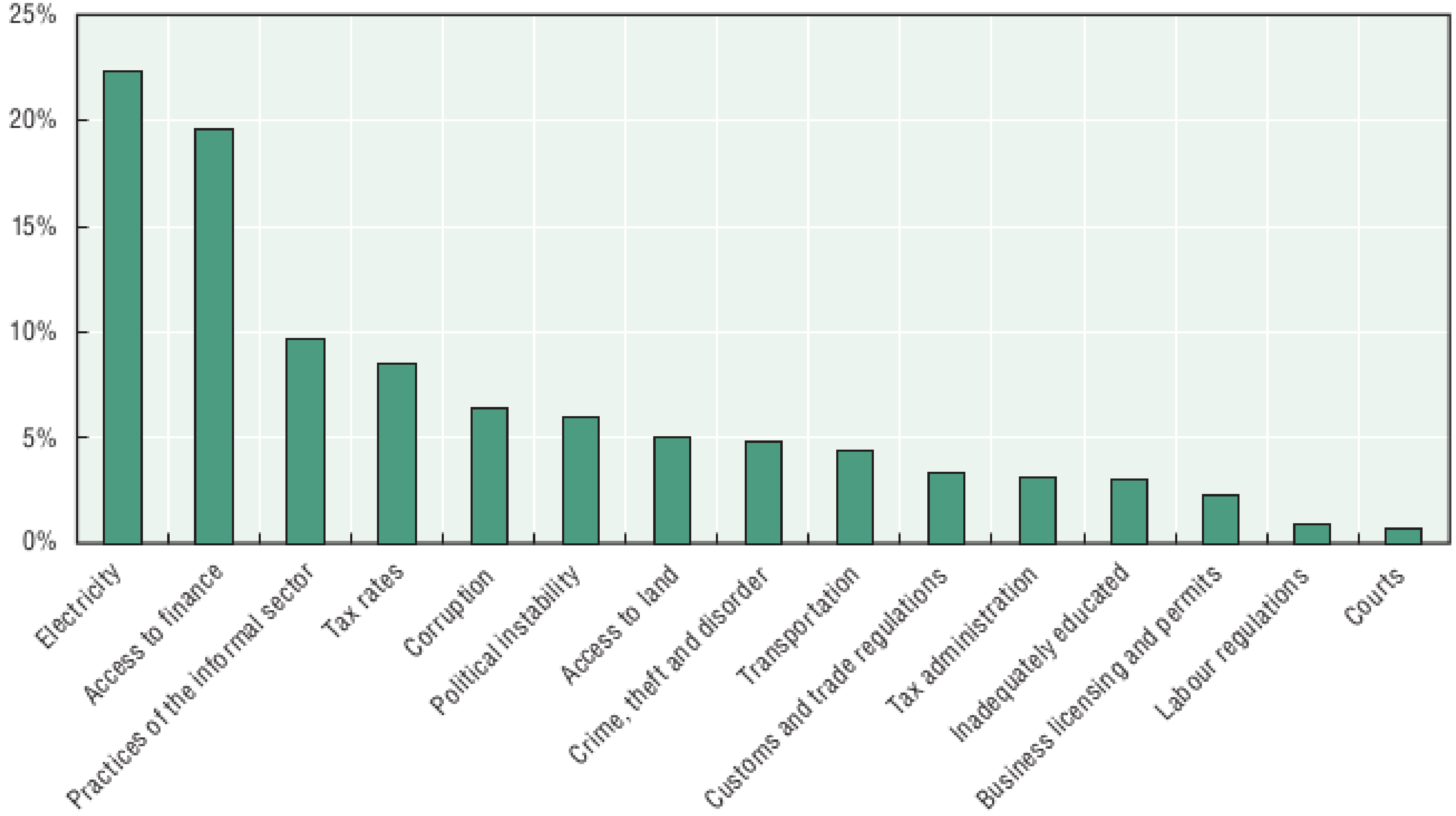




Power is frequently named as
biggest obstacle in building networks -
before skills/capacity and budget.

Power & ICTs

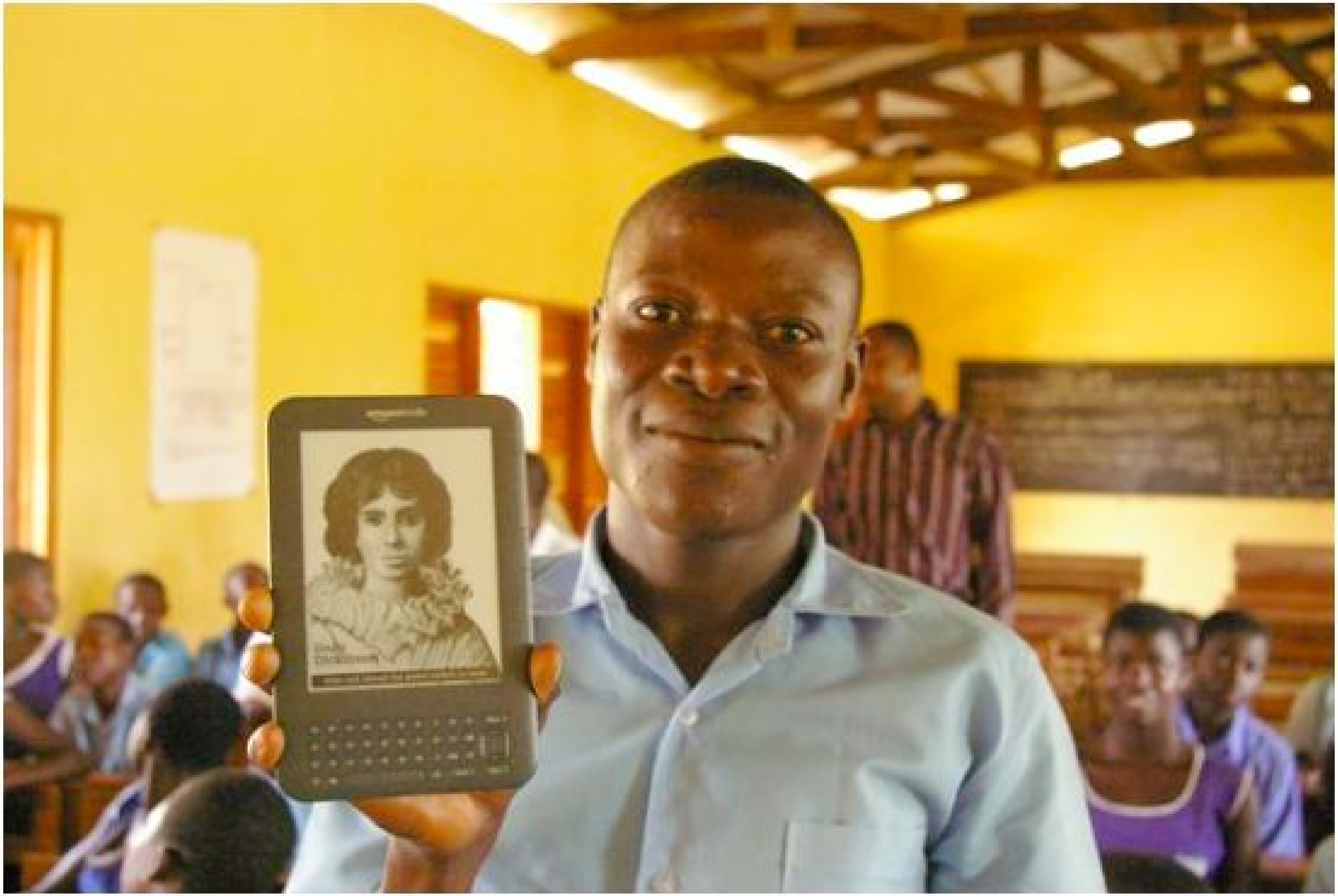
Figure 6.26. **Biggest obstacles to firms in Sub-saharan Africa**



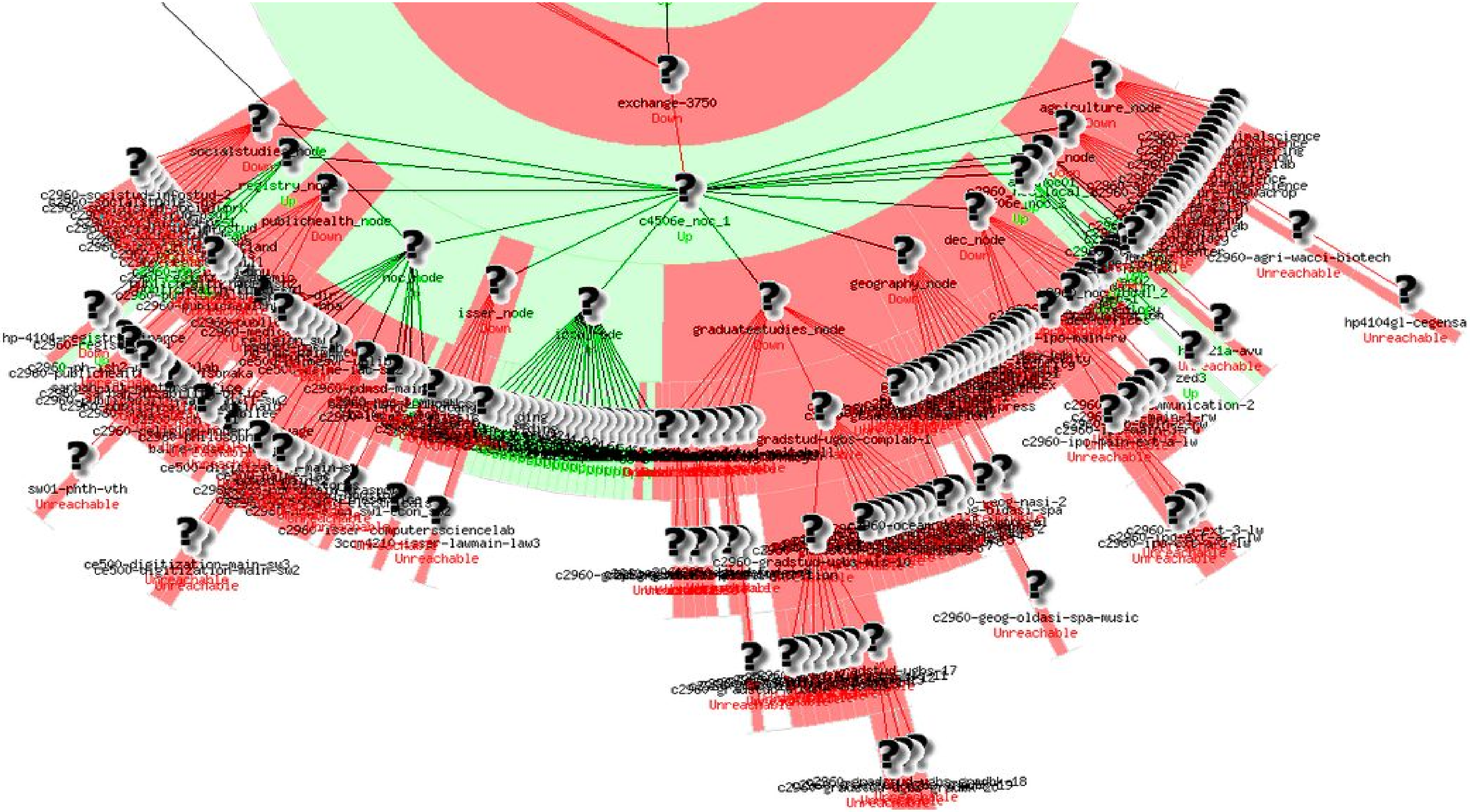
Note: Percentage indicates what firms identify as most important obstacle
Source: World Bank (2006-2011).
StatLink http://dx.doi.org/10.1787/888932600754

Electrical Power is No Longer a Problem in ICT for Development

Published on: Mar 10 2013 by Wayan Vota

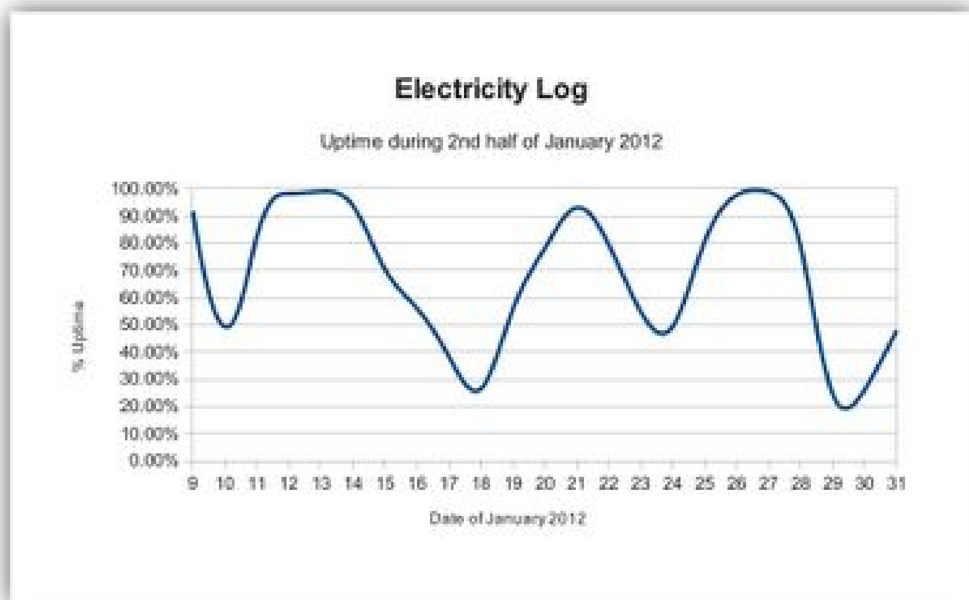


Power and IT Infrastructure



The stable grid is a myth

In most places, the stable grid is nothing but an assumption, a myth rather than a reality.
Even where grids exist, these are often unstable or subject to brown outs and load shedding.



http://peacecorpsdmb.blogspot.it/2012/02/power-or-lack-thereof.html

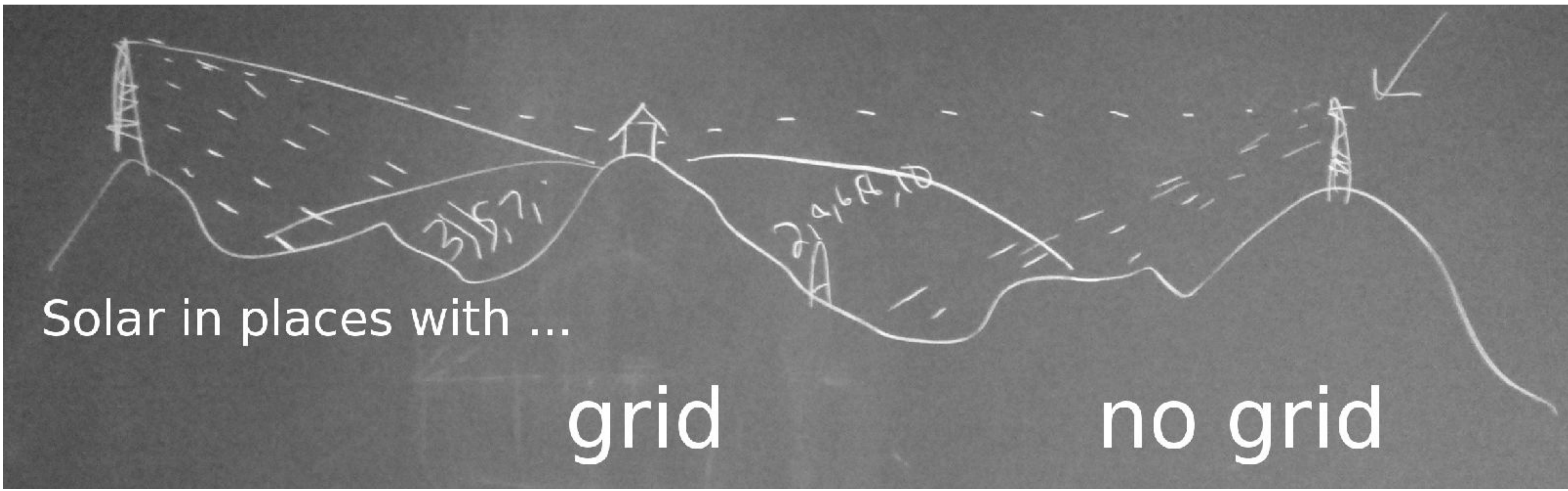
Power outages kill hardware

Unstable power not only leads to
service disruptions,
it also
kills hardware,
leading to
massive losses of investments.

Building networks without solving the power issue
is like
trying to fill a bottomless bucket.

We can wait for the grid myth to become reality,
or we can set a goal:

Only deploy networks and IT infrastructure that you can power autonomously.


Solar in places with ...
grid
no grid
3,5,7,
2,4,6,8,10

Dimensioning a PV system

The main things you need to know:

Your input – how much sun, when, where?
Insolation

Your output – what is the load?
Consumption

What uptime, stability and autonomy is required?
Expectation

Insolation

Insolation data

e.g. From online databases

http://www.wunderground.com/calculators/solar.html

http://www.altestore.com/howto/Solar-Electric-Power/Reference-Materials/S

Photovoltaic Geographical Information System (PVGIS)
http://re.jrc.ec.europa.eu/pvgis/

Remember
real life intelligence and open eyes!

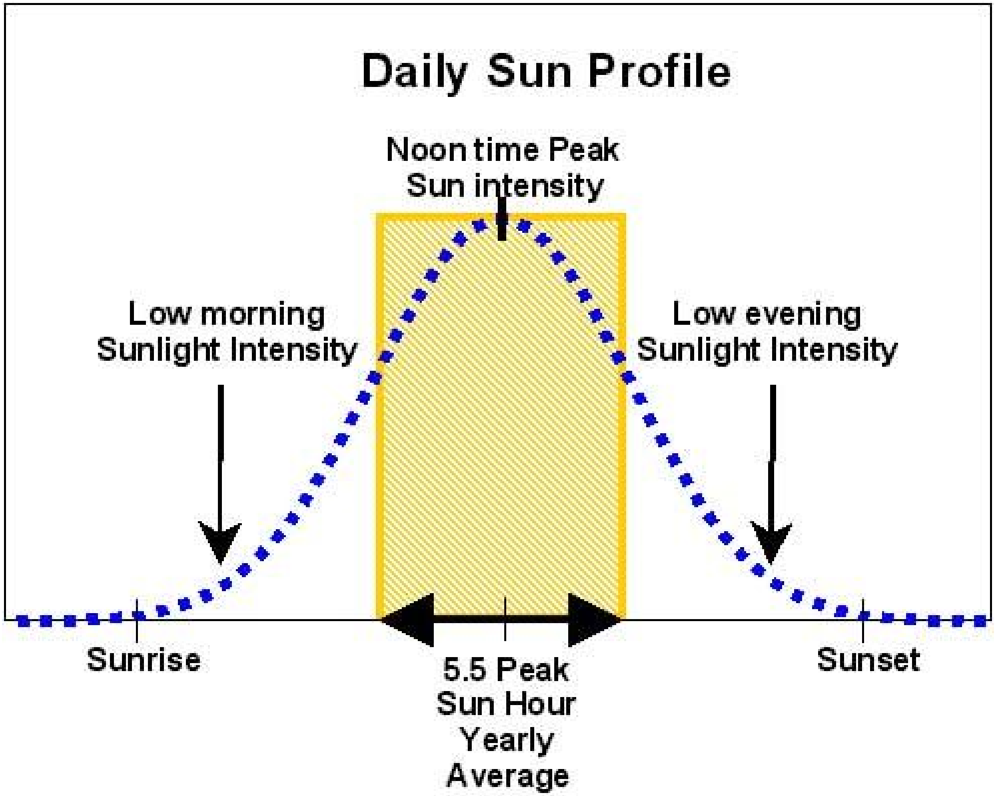
Measure!

Peak sun hours

Insolation:
How many Watts per square meter?

A useful unit:
Peak sun hours (PSH)

Peak =
1 kW/sqm



Dimensioning

Useful quick facts to remember:

Peak: 1 kW/sqm

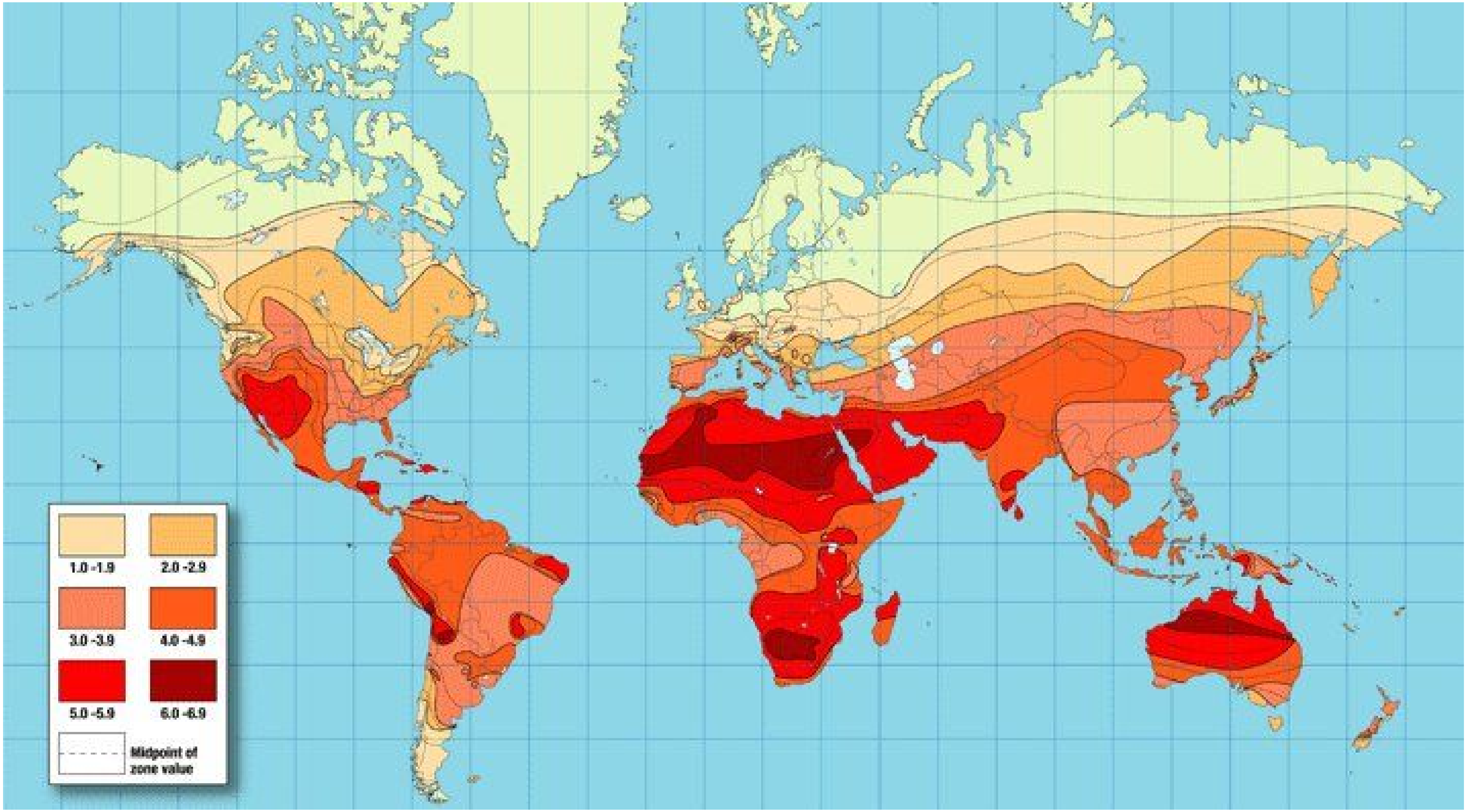
With 15 % efficiency, that gives
150 W/sqm or
7 sqm of panel for 1 kW of output.

Multiply with your PSH, and you know
What you are getting per day.

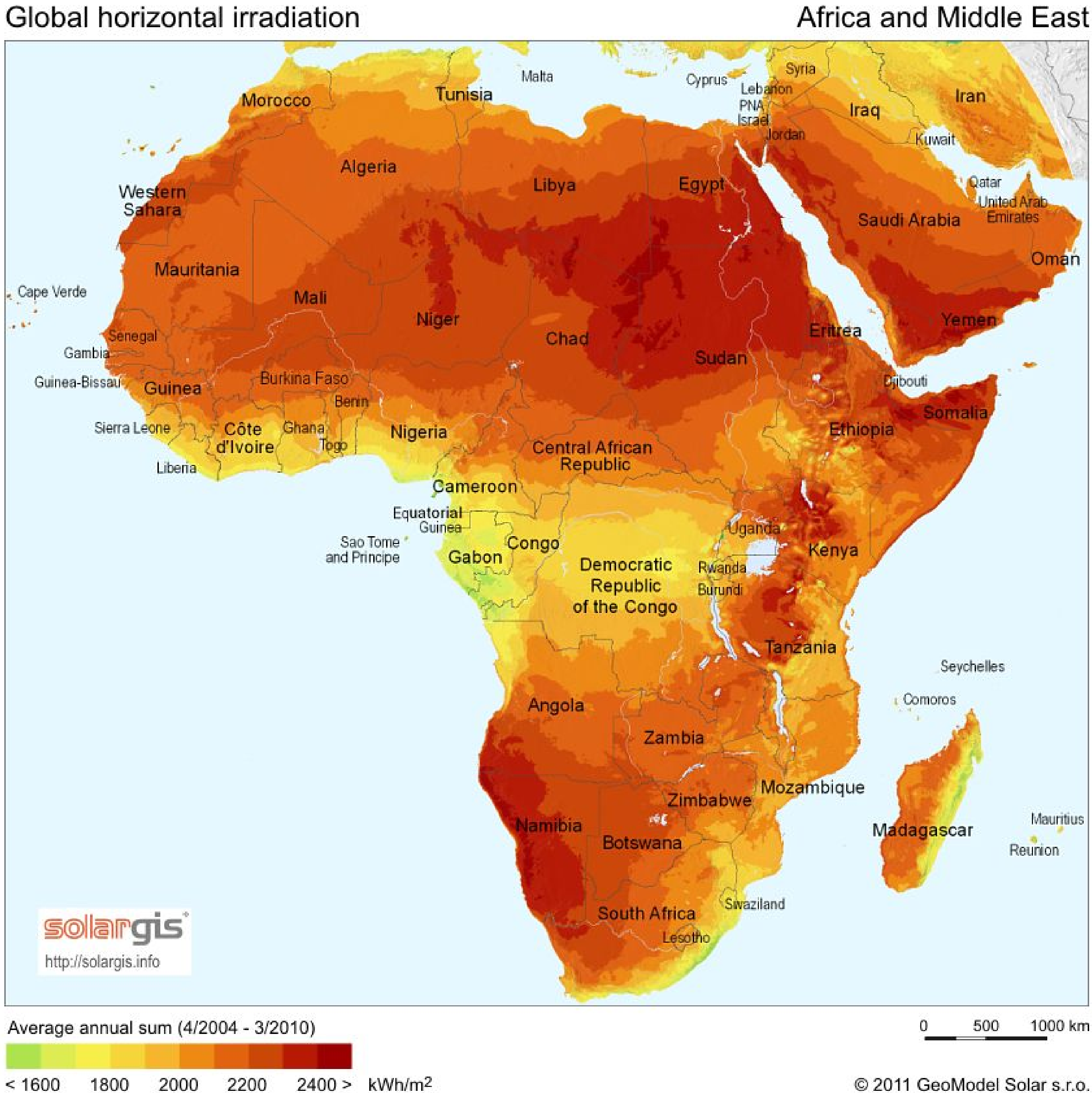
Without words

University of Cape Coast, Ghana

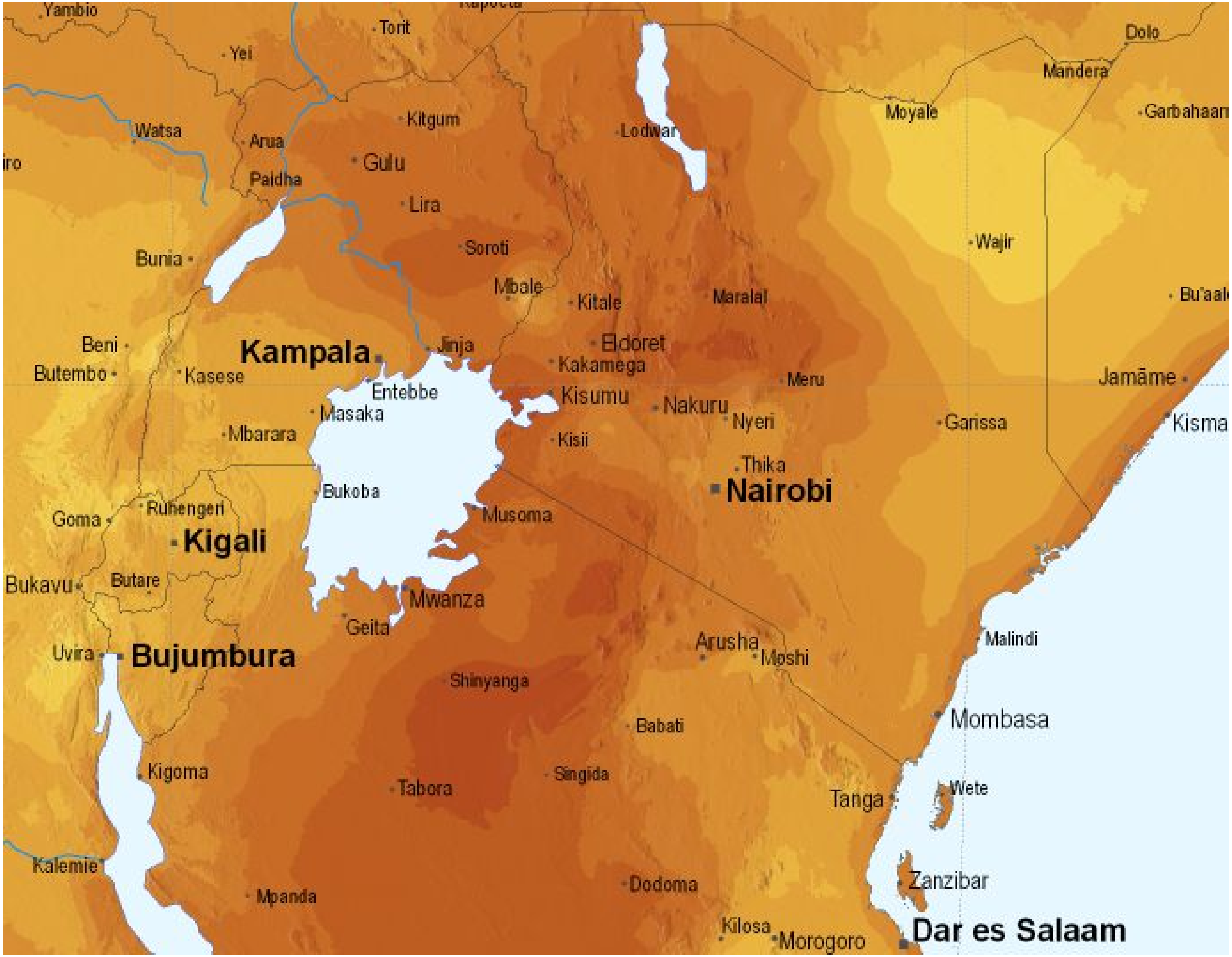
Global insolation



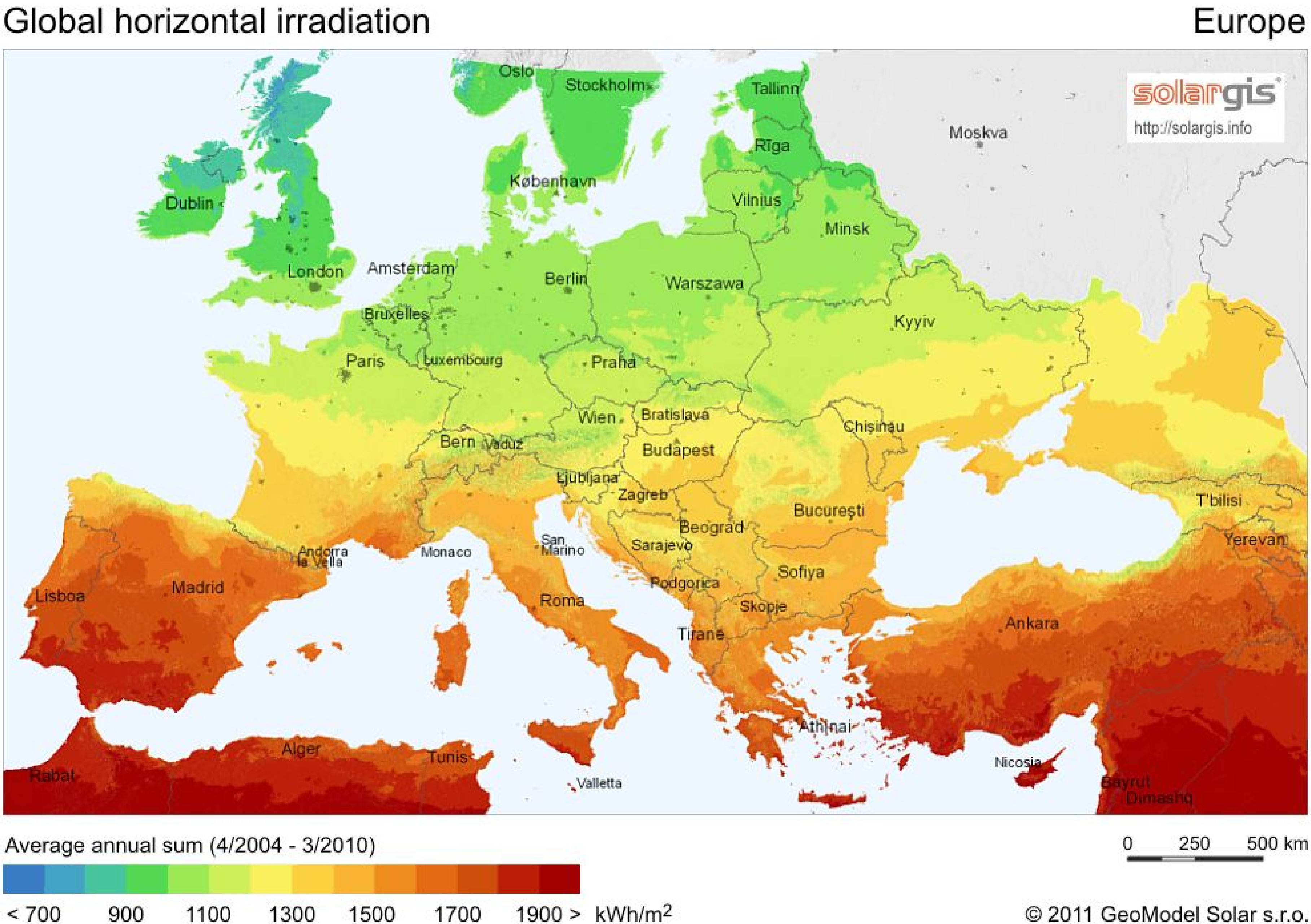
Africa


Global horizontal irradiation
Africa and Middle East
Morocco
Tunisia
Malta
Cyprus
Syria
Lebanon
PNA
Israel
Jordan
Iraq
Iran
Kuwait
Algeria
Libya
Egypt
Qatar
United Arab Emirates
Saudi Arabia
Oman
Western Sahara
Mauritania
Cape Verde
Mali
Niger
Chad
Sudan
Eritrea
Yemen
Senegal
Gambia
Guinea-Bissau
Guinea
Burkina Faso
Benin
Djibouti
Somalia
Sierra Leone
Côte d'Ivoire
Ghana
Togo
Nigeria
Central African Republic
Ethiopia
Liberia
Cameroon
Equatorial Guinea
Sao Tome and Principe
Gabon
Congo
Democratic Republic of the Congo
Uganda
Kenya
Rwanda
Burundi
Tanzania
Seychelles
Comoros
Angola
Zambia
Mozambique
Zimbabwe
Namibia
Botswana
Madagascar
Mauritius
Reunion
South Africa
Swaziland
Lesotho
solargis
http://solargis.info
Average annual sum (4/2004 - 3/2010)
< 1600
1800
2000
2200
2400 >
kWh/m2
0
500
1000 km
© 2011 GeoModel Solar s.r.o.

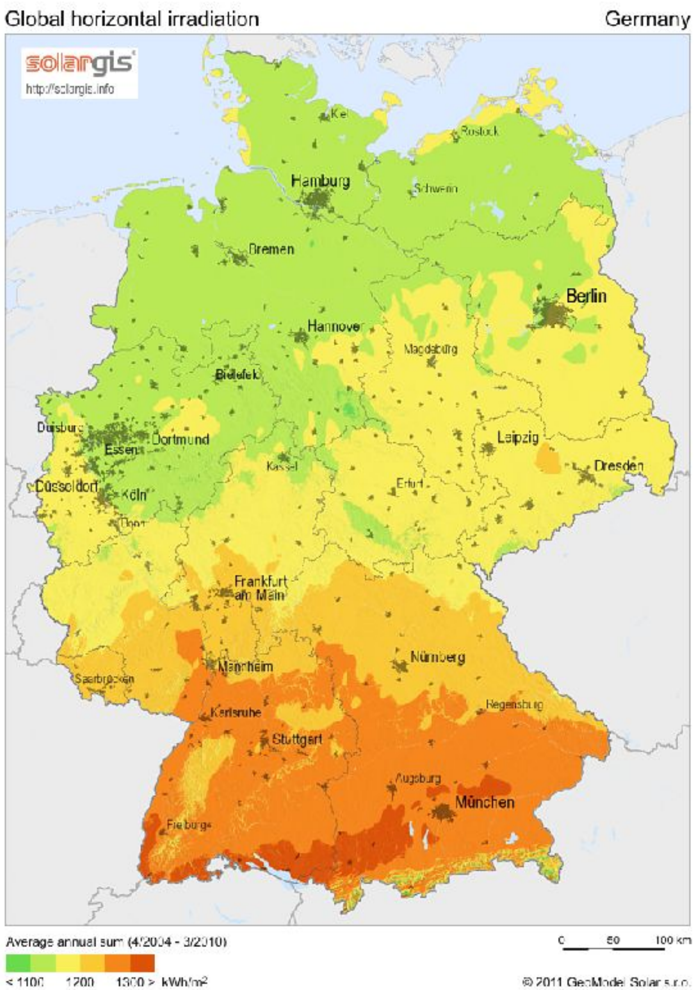
East Africa


Yambio
Torit
Yei
Dolo
Mandera
Watsa
Arua
Kitgum
Lodwar
Moyale
Gulu
Paidha
Lira
Bunia
Soroti
Wajir
Mbale
Kitale
Maralal
Beni
Kampala
Jinja
Eldoret
Butembo
Kasese
Kakamega
Meru
Jamāme
Entebbe
Kisumu
Masaka
Nakuru
Nyeri
Garissa
Mbarara
Kisii
Thika
Bukoba
Nairobi
Ruhengeri
Goma
Musoma
Kigali
Bukavu
Butare
Mwanza
Geita
Malindi
Arusha
Moshi
Uvira
Bujumbura
Shinyanga
Mombasa
Babati
Kigoma
Singida
Tabora
Wete
Tanga
Kalemie
Zanzibar
Dodoma
Mpanda
Kilosa
Morogoro
Dar es Salaam

Europe


Global horizontal irradiation
Europe
solargis
http://solargis.info
Oslo
Stockholm
Tallinn
Moskva
Riga
København
Dublin
Vilnius
Minsk
London
Amsterdam
Berlin
Warszawa
Bruxelles
Kyyiv
Paris
Luxembourg
Praha
Wien
Bratislava
Chişinau
Bern
Vaduz
Budapest
Ljubljana
Zagreb
T'bilisi
Bucureşti
Beograd
San Marino
Monaco
Andorra la Vella
Sarajevo
Yerevan
Sofiya
Lisboa
Madrid
Podgorica
Roma
Skopje
Ankara
Tirane
Athinai
Alger
Tunis
Nicosia
Rabat
Valletta
Bayrut
Dimashq
Average annual sum (4/2004 - 3/2010)
< 700
900
1100
1300
1500
1700
1900 >
kWh/m2
0
250
500 km
© 2011 GeoModel Solar s.r.o.

Got less sun? No big prob! :)



Germany sets world record for solar power generation

By Madonna Gauding Published: June 15, 2012

Posted in: Energy, Environment, Technology

Tags: Fossil fuel subsidies , Germany , Solar energy

Consumption

Loads / Consumption

First rule:

Try to minimize the consumption.

Each Watt of consumption will cost you!

HOW MUCH POWER?

AN OLD BIG COMPUTER: 100 W

A LIGHT BULB: 60 W

AN ENERGY SAVING LIGHT BULB: 5-10 W

A MODERN SMALL COMPUTER: 5W

A LAPTOP: 20-40 W

A LED LIGHT: ~ 3W

Typical power consumptions

Your mobile phone? ....

Arduino: ~ 1 … 5 W (it depends …)

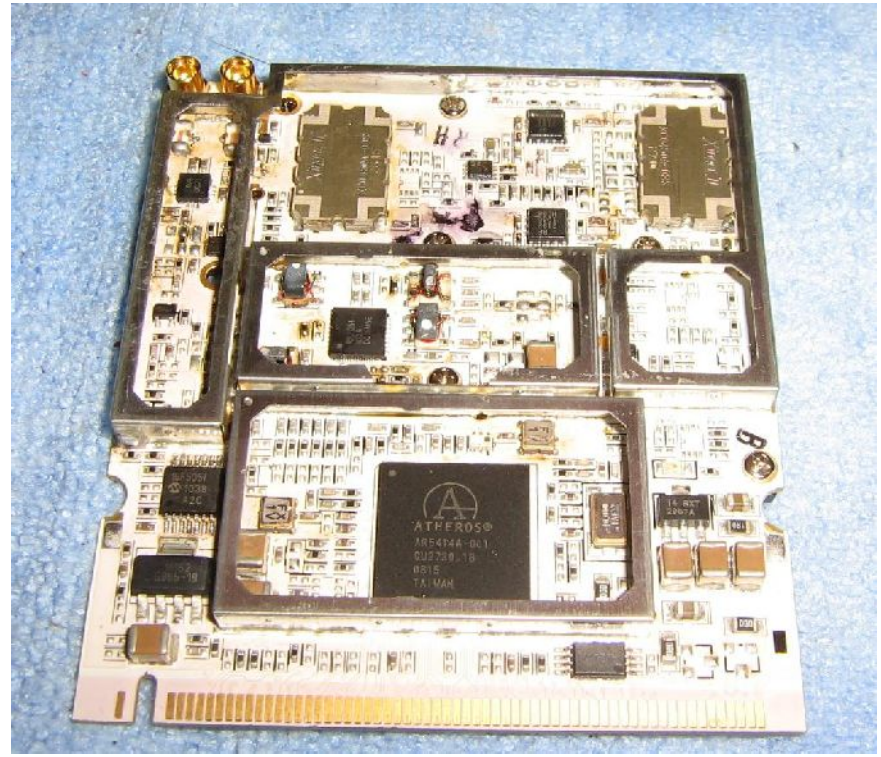
Raspberry Pi: < 5 W

Typical WiFi AP: 2 - 10 W … and more

Carlson TVWS base station: 30-40 W

Doodle labs TVWS card DL-435: 5 W

Example: Doodle Labs DL-435



Operating Voltage

3.3 Volts

Power Consumption

5W @ 30 dBm,
in continuous data transfer mode

3W @ 24 dBm,
in continuous data transmit mode @ 48 Mbps

2W in continuous data receive mode
0.9W in Sleep mode

http://www.doodlelabs.com/products/radio-transceivers/sub-ghz-range/

Example: 6Harmonics TVWS

~~Let's ask! :)~~

We ve asked:

about **25 Watts**
for the 6Harmonics base station

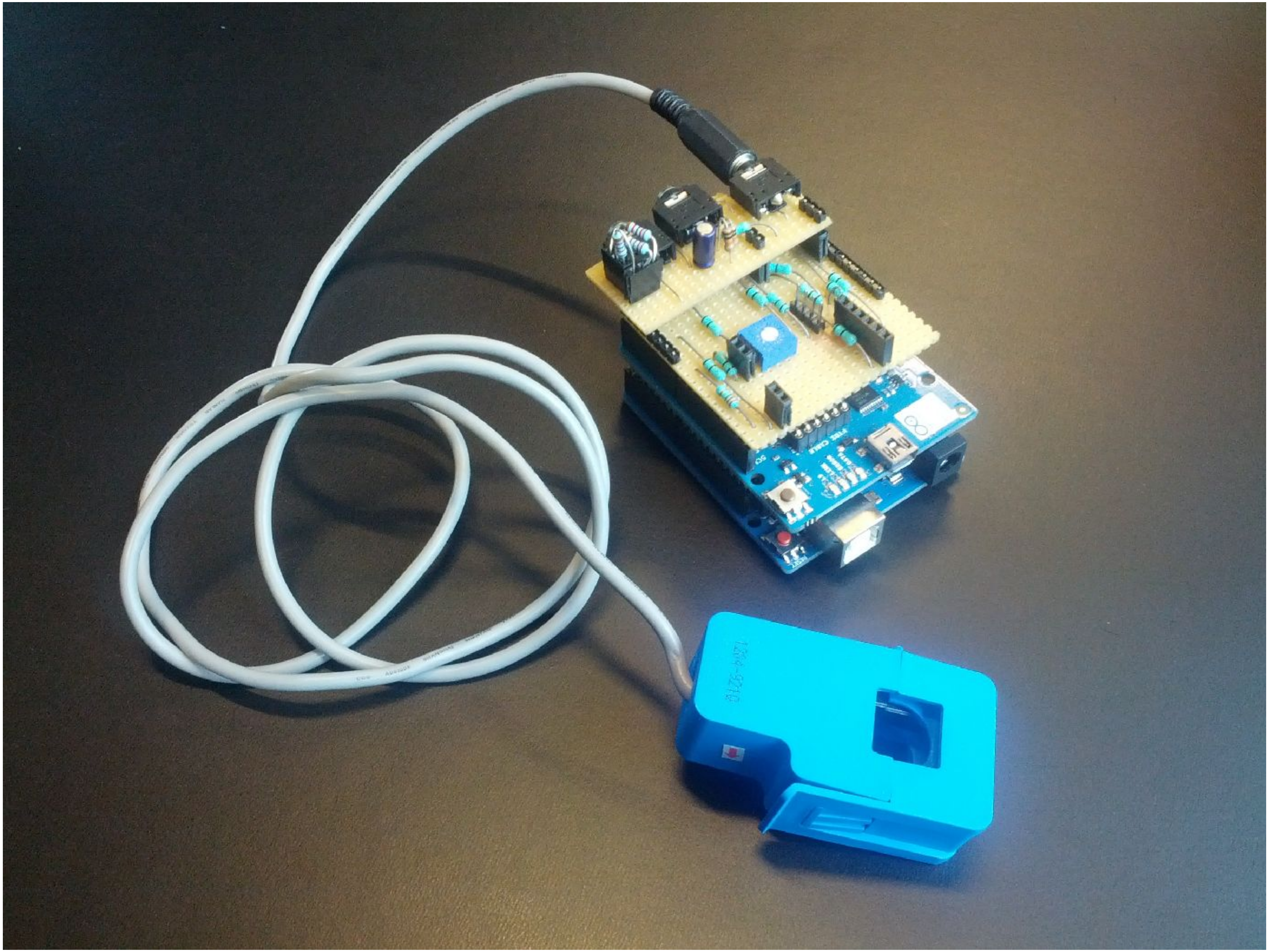
If the datasheet does not say ...

Not good ...

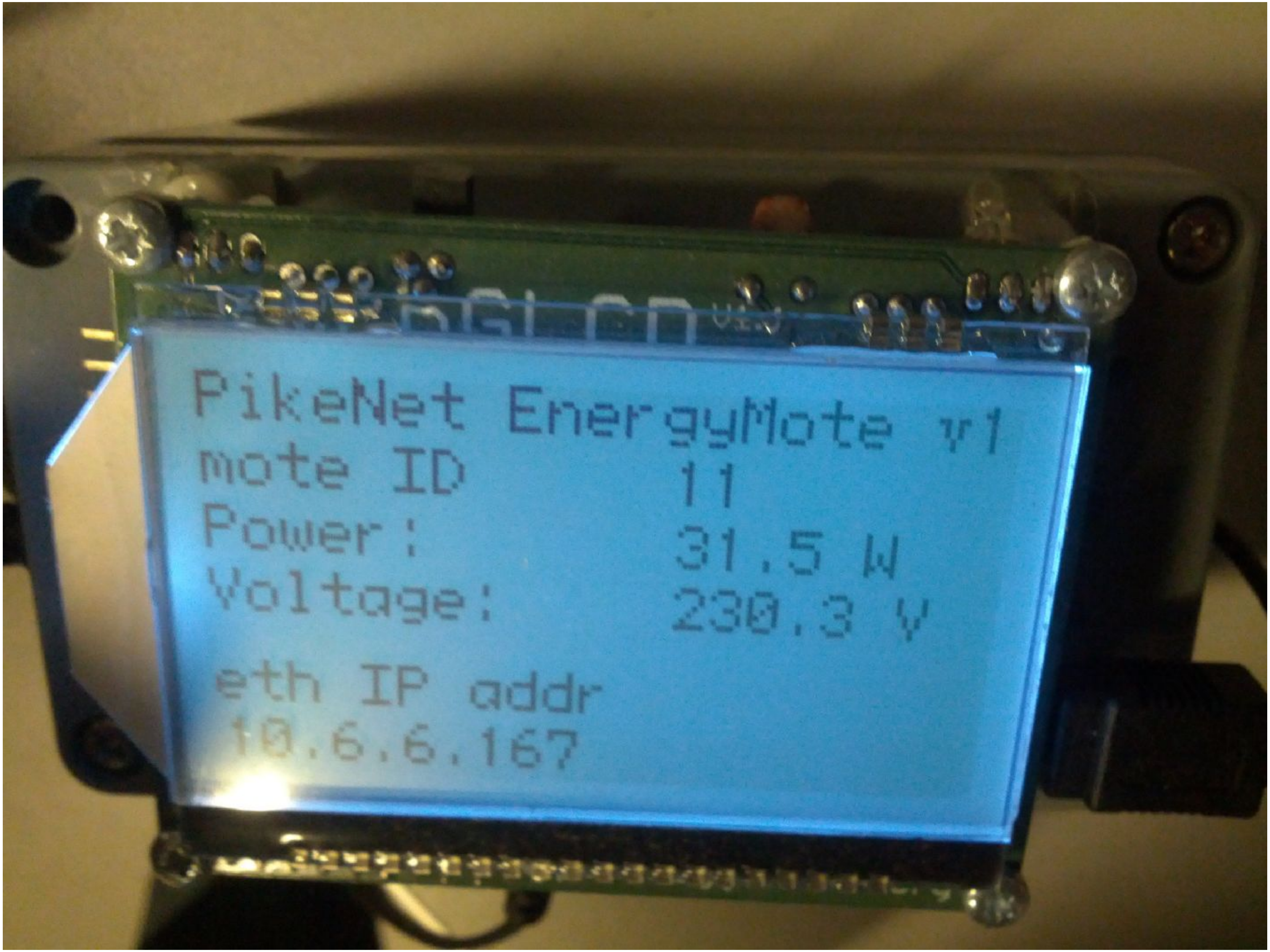
http://www.adaptrum.com/Products_index.htm

Ask!
Read the label!
Check power supply to guess the max!
Measure!

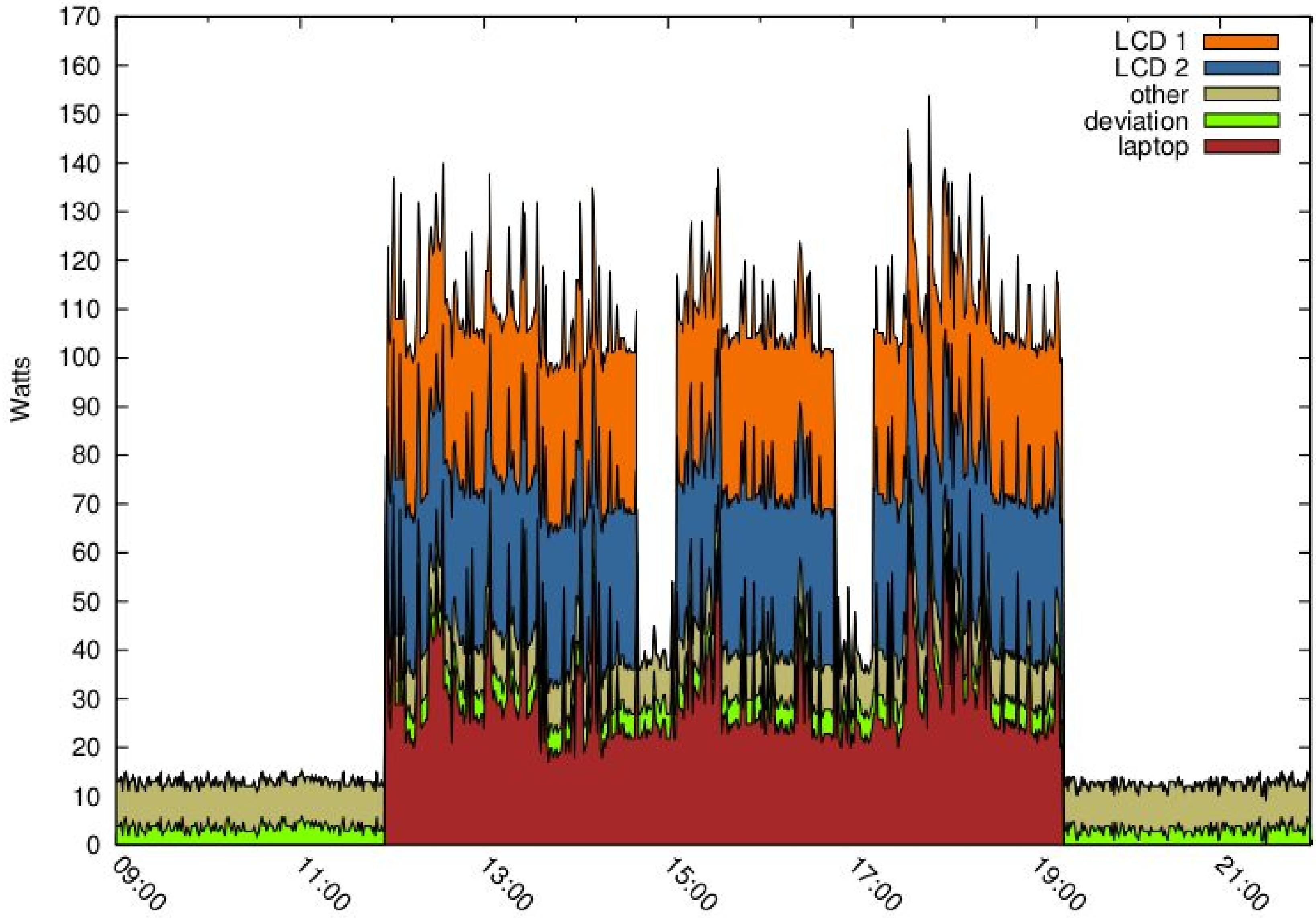
Side comment: Arduinos & Open Energy Monitor



Side comment: Open Energy Monitor



Side comment: Precision measurement of power consumption

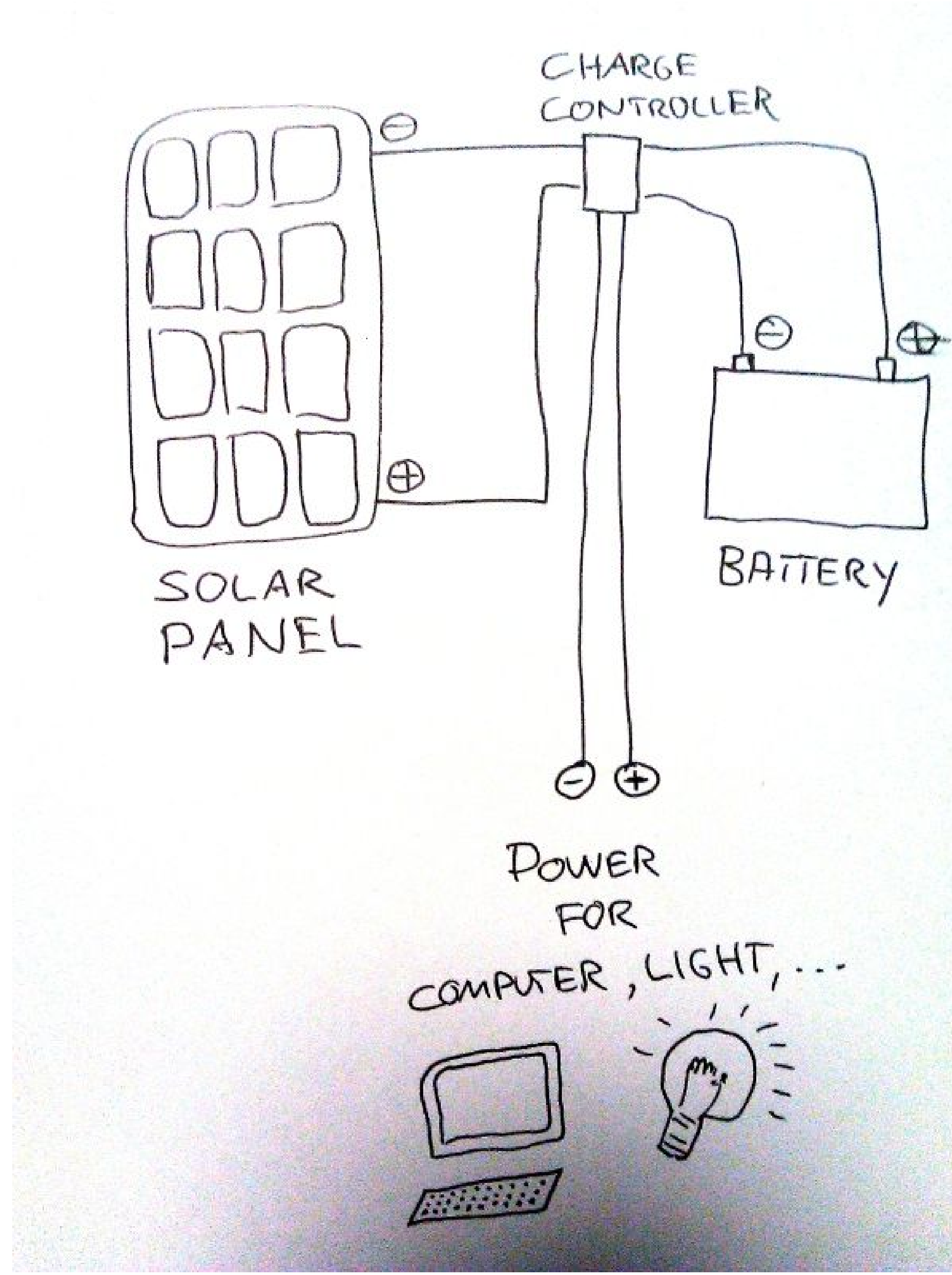


Expectation

Autonomy expectations ultimately depend on the network engineers' and users' educated opinion.

While it might be acceptable for a computer classroom to run out of power during the night or on weekends, for networks we should generally design for near 100% uptime.

Dimensioning



Dimensioning - Approaches

1) All year average approach

2) Worst month approach

3) ”Battery” approach

Formula

The following formula provide the basis for dimensioning:

PSH	peak sun hours (year average or worst month) [h]
Pl	load [W]
Wp	Power (Watt peak) of solar panels [W]
Ep	Energy produced by panels, in Wh/day.
Eff	Efficiency of solar panel [%]
Cb	Capacity of battery [Wh], never be discharged to below 50%.
A	Area of solar panel [sqm]
tO	time of operations without recharge [h]
	tO is at least (24 hrs – PSH), but likely significantly larger
tC	charge time for batteries [h]

Year average approach

Minimum panel size, in Watts peak = P_l x 24 / PSH (year average)

The battery size in Wh may then (optimistically!) be deducted from

(2) $$C_b = 2 * P_l * (24 - PSH(\mathit{year\ average}))$$

Note the factor 2, due to the fact that Batteries

should never be discharged to below 50% of their capacity.

Worst month approach

Minimum panel size = Pl x 24 / PSH (worst month)

The battery size may then be deducted from

(3) $C_b = 2 * P_l * t_o$

Battery approach:

Starting with a more conservative assumption

(4) $\boxed{\text{Battery capacity } C_b = 2 * P_l * t_O}$

we deduct optimistically,

(5) $\boxed{\text{Minimum panel size } W_p = C_b / (2 * PSH)}$

or more conservative,

(6) $\boxed{\text{Minimum panel size } W_p = C_b / (2 * t_C)}$

Powering a 100 W load / PSH

Table 13.1: PSH in different locations.

Location	PSH Year Average [h]	PSH Worst Month [h]
Kenya, Nairobi	6.00	5.00
Germany, Berlin	3.00	1.00
South Africa, Cape Town	6.00	4.00
UK, Cambridge	3.00	1.00
Malawi, Lilongwe	6.00	5.00

Powering a 100 W load

$P_L = 100$ W

Location	PSH Year average [h]	PSH, Worst month [h]	Minimum panel size Year average approach Wp [W]	Minimum panel size Worst month approach Wp [W]	Minimum panel size Battery approach Wp [W]	Battery capacity Minimum Year average approach [Wh]	Battery capacity Minimum Worst month approach [Wh]	Battery capacity Minimum For 3 days operations [Wh]
Kenya, Nairobi	6.00	5.00	400	480	380	3600	3800	7200
Germany, Berlin	3.00	1.00	800	2400	2300	4200	4600	7200
South Africa, Cape Town	6.00	4.00	400	600	500	3600	4000	7200
UK, Cambridge	3.00	1.00	800	2400	2300	4200	4600	7200
Malawi, Lilongwe	6.00	5.00	400	480	380	3600	3800	7200

Powering a 100 W load

Table 13.2: Minimum Panel Size in different locations.

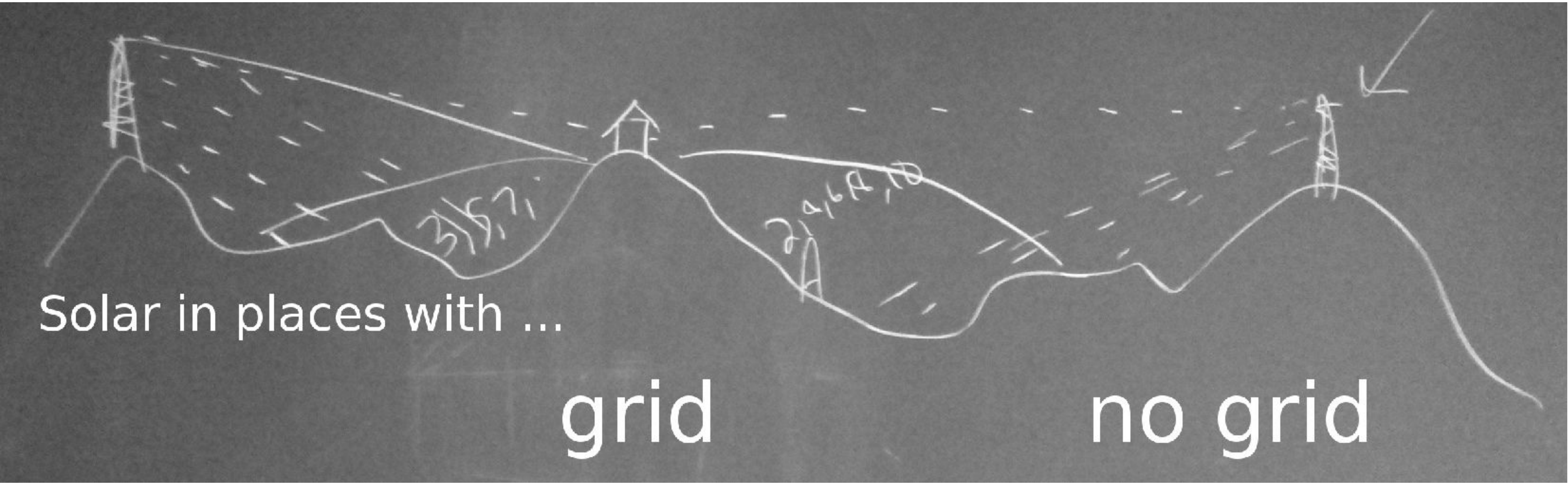
Location	Minimum Panel Size Year Average Approach [W]	Minimum Panel Size Worst Month Approach [W]	Minimum Panel Size Battery Approach [W]
Kenya, Nairobi	400	480	380
Germany, Berlin	800	2400	2300
South Africa, Cape Town	400	600	500
UK, Cambridge	800	2400	2300
Malawi, Lilongwe	400	480	380

Powering a 100 W load

Table 13.3: Battery Capacity in different locations.

Location	Battery Capacity Minimum Year Average Approach [Wh]	Battery Capacity Minimum Worst Month Approach [Wh]	Battery Capacity Minimum For 3 Days Operation [Wh]
Kenya, Nairobi	3600	3800	7200
Germany, Berlin	4200	4600	7200
South Africa, Cape Town	3600	4000	7200
UK, Cambridge	4200	4600	7200
Malawi, Lilongwe	3600	3800	7200

Economics



We can compare the cost of solar power to
Grid electricity
or
Diesel generator electricity

Economics

CAPEX	initial capital expenses
PSH	peak sun hours (year average) [h]
YOP	years of operation
MF	annual maintenance factor for replacement of equipment, etc.
PD	price of diesel per liter
HOP	hours of operation per year (for Diesel generator)
CD	Diesel consumption [Liter per kWh]

Cost of solar and diesel power

Table 13.4: Cost per kWh [$], in year of operation.

			1	5	10	20	30
Solar	PSH	Accumulated CAPEX	3000	4200	5700	8700	11700
DK	2	Cost/kWh	4.11	1.15	0.78	0.60	0.53
KE	5	Cost/kWh	1.64	0.46	0.31	0.24	0.21
Diesel	Price/Liter [$]	Accumulated CAPEX	500	700	950	1450	1950
DK	1.8	Cost/kWh	0.60	0.56	0.55	0.44	0.55
KE	1	Cost/kWh	0.36	0.32	0.31	0.31	0.31

Remark:
these calculations are very Diesel friendly! Too friendly!
Diesel needs to be transported too, generators break, etc ..
Please do your own calculations!

Year of break-even

After how many years
is solar cheaper than diesel?

$$CAPEXSOLAR/((PSH * 365)(CAPEXDIESEL/8760 + P_D * C_D))$$

In most reasonably sunny places,
It will be some years … up to 10 years,
Of course depending on input values!

Comparison with grid power

As of 2013, solar electricity reaches approximately

$ 0.20 / kWh

(in sunny climates, over 25 years) -

What do you pay for the grid kWh?

Power questions

I come from (Country/City): ____

The cost of grid electricity per kWh is ______________________________________

Price of Diesel (for Generators) per Liter or Gallon is _________________________

The price of Diesel generated electricity per kWh is ___________________________

The price of a 100 W solar panel is ____

The price of solar generated electricity (over __ years) is ___________________

Grid electricity is (stable / unstable / not there at all)?

____

What else i would like to say about power at my place:

Thank you! sebastian@nsrc.org

Cost of grid power

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$ 0.26 / kWh

Solar break even after ~ 9 years

… and the other 42 countries?

https://en.wikipedia.org/wiki/Electricity_pricing#Global_electricity_price_comparison

Cost of grid power, Africa

In 2010,
the average effective electricity tariff in Africa was $ 0.14/kWh,
vs. $ 0.18/kWh in production costs.

Source: African Development Bank 2013, http://www.howwemadeitinafrica.com/why-africas-electricity-generation-costs-are-among-the-highest-in-the-world/24508/

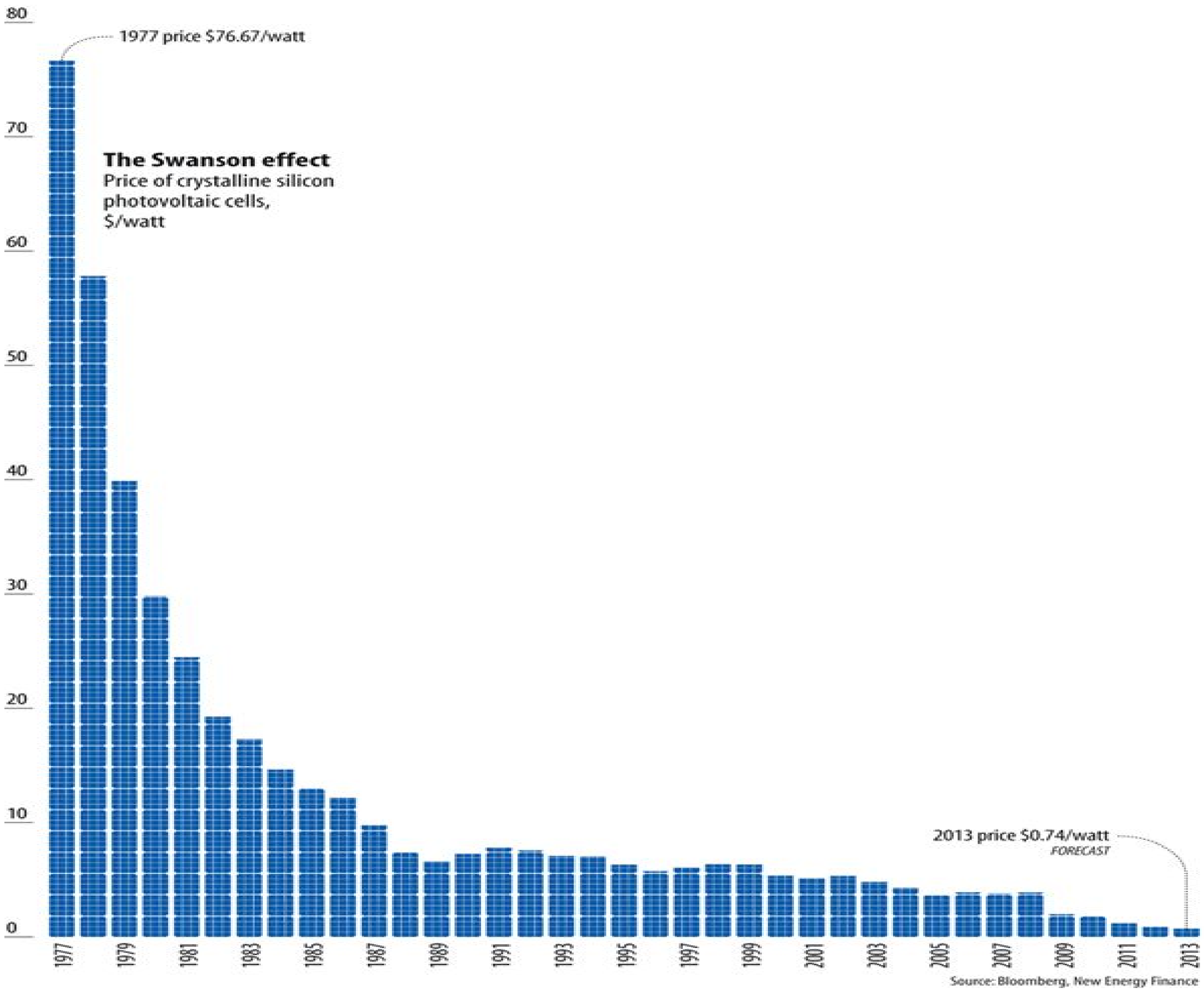
The average effective tariff in South Asia was $ 0.04/kWh,
while that for East Asia was $ 0.07/kWh.

Economics (up against 15 cents/kWh)

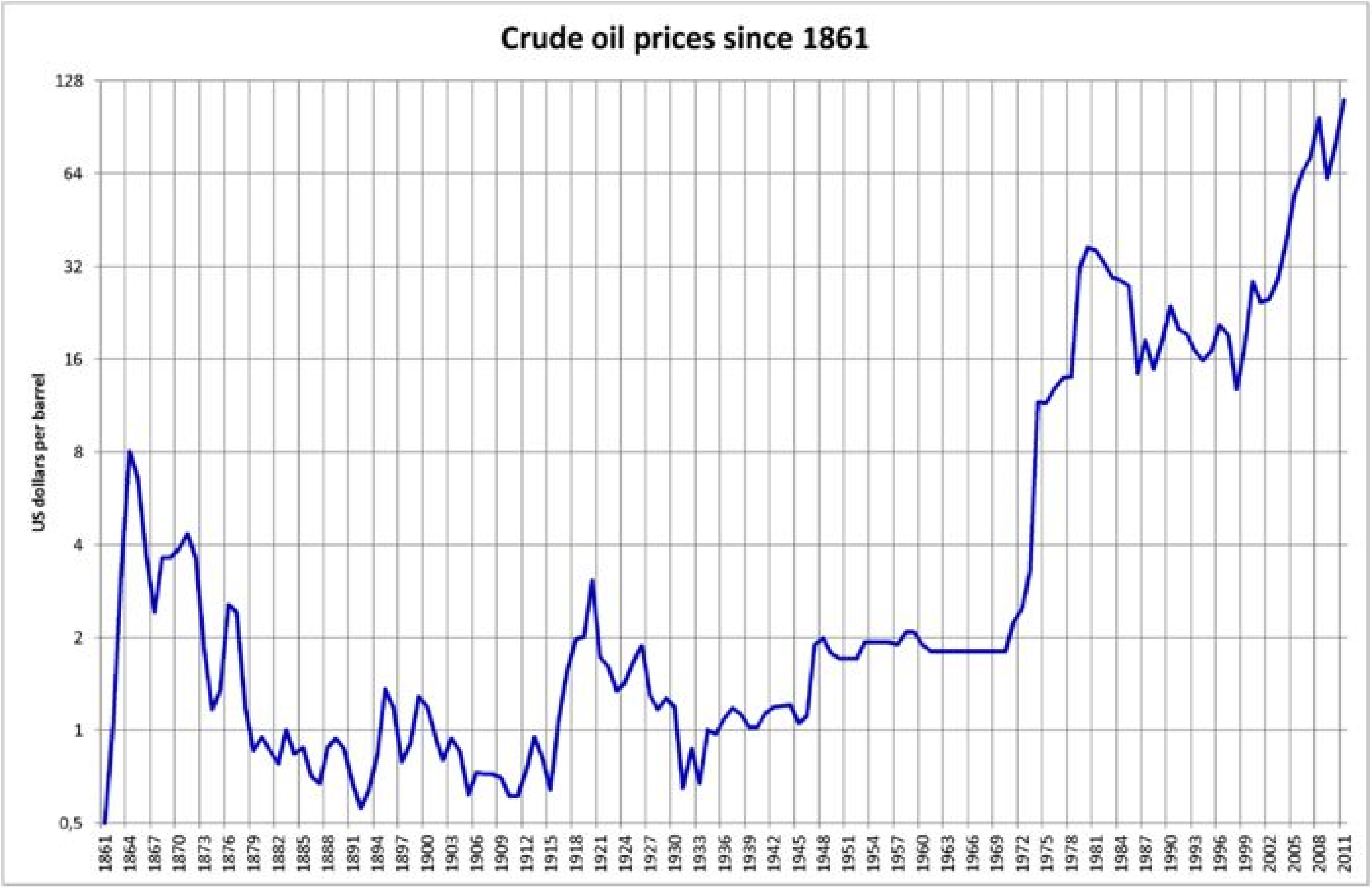
Table showing average cost in cents/kWh over 20 years for solar power panels

		Insolation [peak sun hours] 6				4				2
Cost [$/W]		2400 kWh/ kWp•y	2200 kWh/ kWp•y	2000 kWh/ kWp•y	1800 kWh/ kWp•y	1600 kWh/ kWp•y	1400 kWh/kWp•y	1200 kWh/kWp•y	1000 kWh/kWp•y	800 kWh/kWp•y
	200 $/kWp	0.8	0.9	1.0	1.1	1.3	1.4	1.7	2.0	2.5
0.5	600 $/kWp	2.5	2.7	3.0	3.3	3.8	4.3	5.0	6.0	7.5
1	1000 $/kWp	4.2	4.5	5.0	5.6	6.3	7.1	8.3	10.0	12.5
	1400 $/kWp	5.8	6.4	7.0	7.8	8.8	10.0	11.7	14.0	17.5
	1800 $/kWp	7.5	8.2	9.0	10.0	11.3	12.9	15.0	18.0	22.5
2	2200 $/kWp	9.2	10.0	11.0	12.2	13.8	15.7	18.3	22.0	27.5
	2600 $/kWp	10.8	11.8	13.0	14.4	16.3	18.6	21.7	26.0	32.5
3	3000 $/kWp	12.5	13.6	15.0	16.7	18.8	21.4	25.0	30.0	37.5
	3400 $/kWp	14.2	15.5	17.0	18.9	21.3	24.3	28.3	34.0	42.5
4	3800 $/kWp	15.8	17.3	19.0	21.1	23.8	27.1	31.7	38.0	47.5
	4200 $/kWp	17.5	19.1	21.0	23.3	26.3	30.0	35.0	42.0	52.5
	4600 $/kWp	19.2	20.9	23.0	25.6	28.8	32.9	38.3	46.0	57.5
5	5000 $/kWp	20.8	22.7	25.0	27.8	31.3	35.7	41.7	50.0	62.5

The future - solar



The future - oil



Q & A

Examples, cases, discussion

Some examples: Kopan, Nepal

Some examples: COSMGrid

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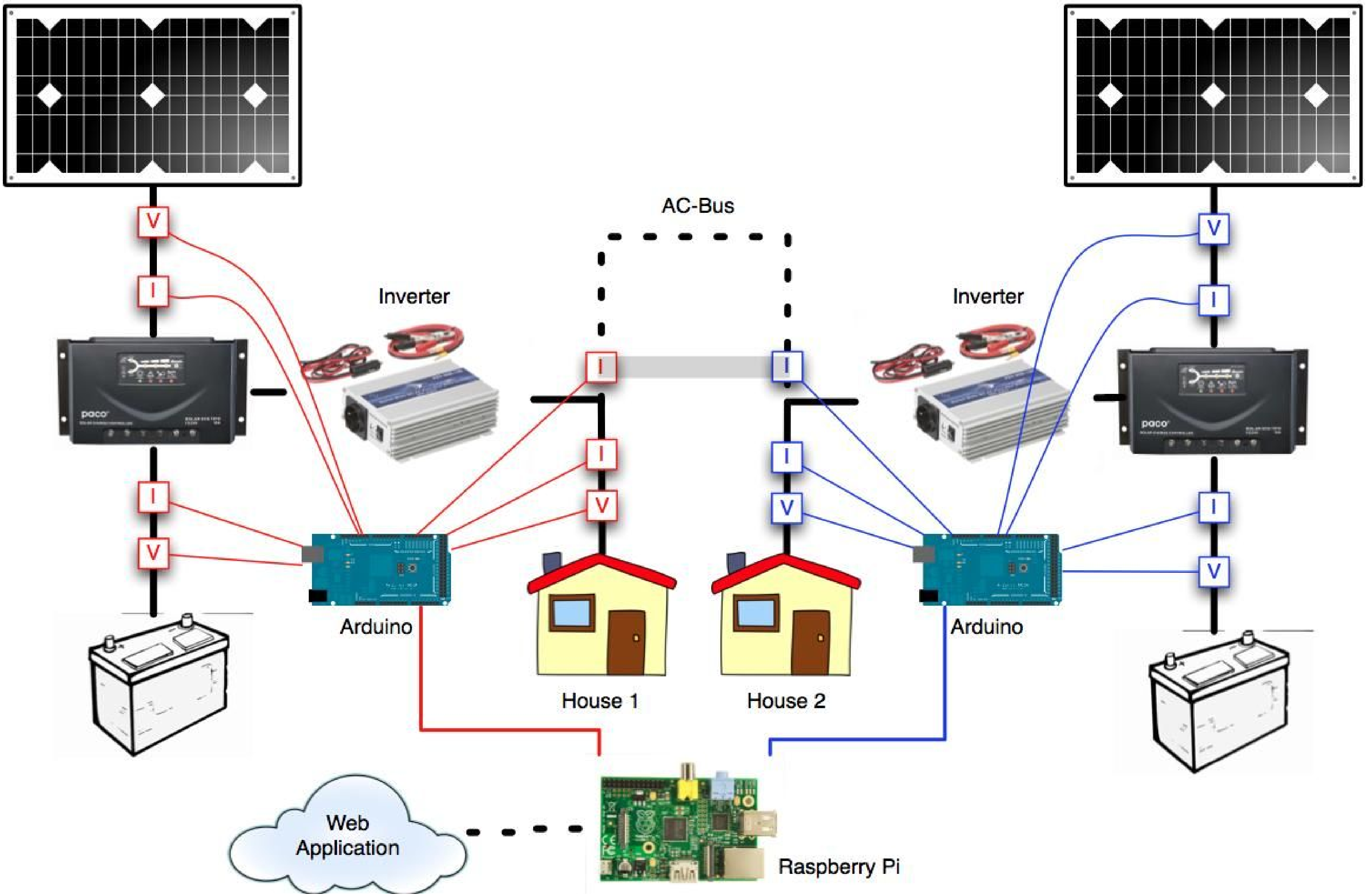
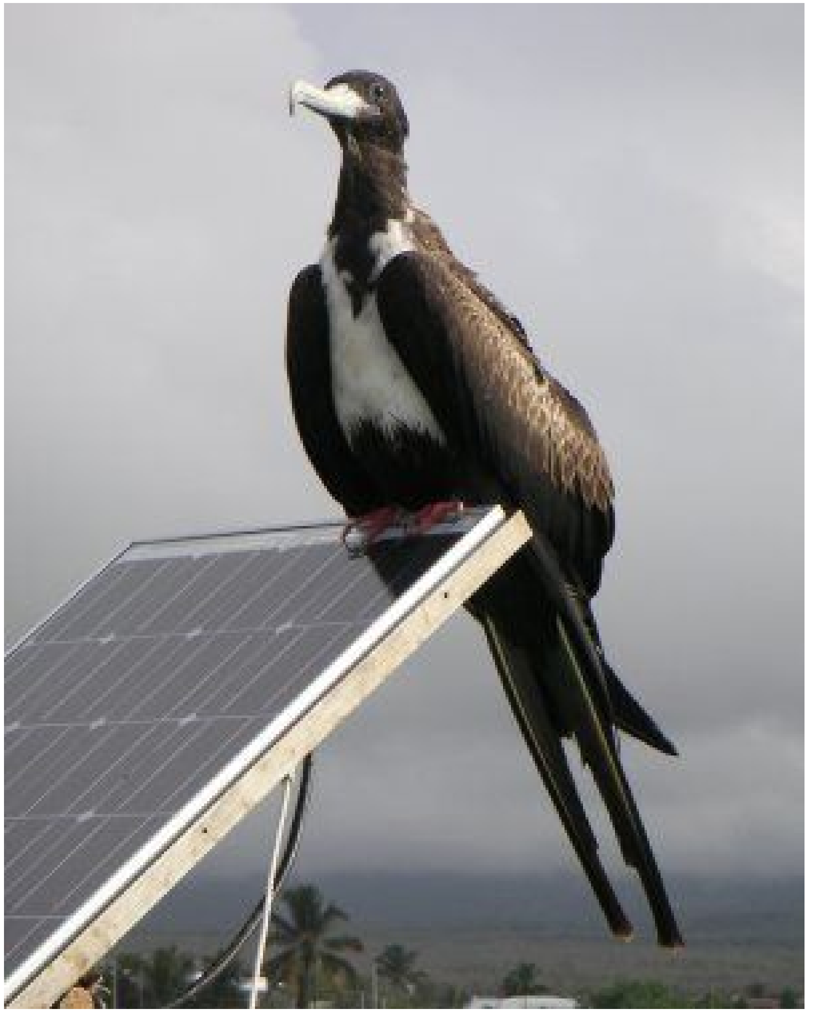


Some examples: Guam

Some examples: TVWS Kenya

Thank you!



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